CARBOFURAN AND WILDLIFE POISONING:

GLOBAL PERSPECTIVES AND FORENSIC APPROACHES

EDITOR
Ngaio Richards

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Preface

Whatever you do will be insignificant, but it is very important that you do it
Mohandas Karamchand Gandhi

This book was initiated in 2009, in response to reports of wildlife mortality from field colleagues in India and Kenya that were tantamount to a distress signal. The unfortunate reality, however, is that carbofuran has been poisoning wildlife for the better part of 40 years. Here, we explore historic and very current incidents of wildlife mortality arising from both misuse (i.e., baiting and intentional poisoning), and legal applications of the compound, to crops. The distinction is very important because each issue elicits a certain response and requires a different approach; in the case of intentional misuse, manufacturers can and do argue that they provide instructions on the product label and that use in violation of these instructions (such as that detailed in Chapters 3 to 7) is outside their remit. In theory, the risks posed by some compounds can be minimised by cracking down on illegal use, by implementing proper management practice (which may include reducing a product's usage or concentration) or by adjusting use to take into consideration patterns of wildlife activity. In practice, the application of such mitigative measures can be far more challenging. Chapter 7 (Latin America) outlines field trials used to measure the effectiveness of mitigative measures (i.e., gustative repellants, colouration and camouflaging) in reducing the mortality of avian species during agricultural applications of carbofuran. Although in this particular case the camouflaging method offered effective protection, other mitigative measures investigated did not. It was noteworthy in this instance that the effectiveness of the gustative repellents was surpassed by the inherent toxicity of the compound. In other words, birds that ingested seeds treated with gustative repellents were poisoned before the repelling properties could even come into effect. In essence, carbofuran has the unpleasant distinction of being so hazardous to wildlife that it simply cannot be effectively regulated or managed accordingly without mortality. The case is made in Chapter 8 (which meticulously chronicles mortality in the United States and Canada arising from labelled usage) that the sole condition under which carbofuran can be safely applied is if an area is already entirely devoid of wildlife. This is why, over and beyond efforts to address alternative management practices, there has been such a strong movement to ban it.

Loss of livelihood or basic sustenance, and the decimation of wildlife species, many of them emblematic and heavily tied to biological richness or tourism potential, all understandably bring out powerful emotions in people. Cultural, socioeconomic and political factors further cloud the use and misuse of carbofuran. To facilitate navigation through such issues, a key objective of this book was to clearly lay out the incontrovertible facts about carbofuran, namely, its chemistry, mode of action, environmental fate, the analytical methods used to detect it (all covered in Chapter 1), the farming, agricultural practices and crops on which it is applied, and some of the laws and regulatory mechanisms in place regarding it, from country to country.

A substantial body of sound analytical evidence has been gathered in the United Kingdom (Chapter 6) and in the United States and Canada (Chapter 8). However, the reader will note the difficulties that even these 'developed' countries have had when it comes to reining in the use of carbofuran. Such

countries have fought to ban carbofuran for decades despite having firm regulations and seemingly irrefutable mortality evidence. Less ‘developed’ parts of the world continue to struggle to gather the most basic forensic data, to record and report the anecdotal evidence, and try to assemble their case against the continued use of carbofuran. In recognition that not all countries are on an even footing in terms of having the resources and capacity required to meet this challenge, another objective of this book was to consolidate the cumulative body of work available in the hope that this would help support current initiatives and catalyse further research. Such information also effectively illustrates the extent of the resources needed, and the magnitude of the task at hand. In response to this, royalties received from the book will go into a research fund established to further develop the contaminants monitoring and detection system in Kenya.

To provide a balanced perspective, the relative threat posed by other poisons and pesticides worldwide is also considered. In some regions, carbofuran emerges as one of the worst offenders whereas in others (for example in India, see Chapter 4), it is only one of many compounds used. In most of the cases presented in this book, population growth is at the root of the reported poisonings, by increasing competition between humans and wild animals for access to increasingly limited resources. ‘Leisure-based’ human-wildlife conflict, as a result of recreational hunting, is also described (see Chapter 6).

As a species, we are so often intolerant of others, and commonly very unwilling to share resources. However, poverty and hardship in less developed countries often leaves little space for compassion towards wildlife. Wild animals feed on crops to access what are, to them, readily available and abundant food sources. They may in turn damage property, in response to increasing encroachment on what is after all their habitat. Like humans, wildlife is running out of living space. As long as these conditions prevail, wildlife will continue to be persecuted, using whatever means are available.

The reader will note that in certain chapters, relatively few references have been cited, that the interval between referenced studies is patchy, or that few recent references are provided. Unfortunately, these discrepancies simply reflect the fact that little information has been amassed regarding wildlife poisoning incidents in that particular area or, that there are large temporal gaps between studies. Such issues are highlighted where appropriate. Many key documents and references came to light during the consultation for, and assembly of, this book. A list of seminal references and analytical protocols not included in this book can be obtained from the editor, via the publisher. A more technical discussion regarding the chemistry and fate of carbofuran in tropical soils is also available upon request. Readers are encouraged to contact the editor if they encounter any difficulties in accessing references mentioned within the book. The editor would also like to draw attention to the lack of material available for much of Asia, especially for Pakistan, China and Thailand. These are important areas for which we were only able to obtain limited information. Colleagues with information regarding these geographical zones, or those wishing to share any new information not already covered in this book, are invited to contact the editor so that these can be collated separately for dissemination.

Above all, the editor wished to give those who have witnessed animals succumbing to poisoning without being able to stop it and those whose best efforts have been undermined, the chance to voice their profound frustration, anguish and sense of helplessness. The hope is that individuals will draw some strength from the work of others which is often going on in parallel, without their knowledge. During a discussion in Nairobi in the spring of 2010, a friend and colleague (Martin Odino, co-author of Chapter 3) described conservation as a ‘sad profession, the science of tremendous loss in the face of short-term gain’. Given the importance of any reprieve achieved, no matter how small or short-lived, we must persevere. Considering the magnitude of the loss in biodiversity already sustained (or looming), we can do nothing else. However, we can move forward with hope, in support of the tenacity shown by the people right in the midst of such issues, as exemplified by those who have contributed to this book. Here, we have tried to provide the best available science to illustrate the risks posed by carbofuran to wildlife worldwide, whether from abuse, misuse or legal practice. As for the future of this insidious compound and the steps that will follow, the reader must carefully consider the evidence and exercise his or her own judgement.

Acknowledgements

This book balances the best available science with compelling firsthand narrative. Much of the information has been consolidated or disseminated for the first time and I am immensely grateful to be able to include it. Over the last three years, my contributors have endured innumerable questions and diligently gathered obscure bits of information in the midst of their infernally busy schedules. I commend them for the dedication which they show in their work and for their ability to address the issue of wildlife poisoning both objectively and passionately.

The support of the Analytical Chemistry Trust Fund of the Royal Society of Chemistry and the John Ray Trust enabled me to travel to Kenya in early 2010 to experience for myself some of the logistical constraints both in the field and laboratory, to gain a better grasp of the issues unfolding there and to speak at length with stakeholders. My editorial task was lightened considerably by the solid work of my contributors, many also serving as reviewers, and by those who commented on various chapters and sections, especially: Darcy Ogada, Alana Balogh, Stephen Donovan, Caroline Kennedy, Carol Meteyer, Michael Fry and a number of individuals who wished to remain anonymous. Mark Taggart went above and beyond the call of duty as a reviewer, and his feedback was indispensable. Special thanks are extended to my editor Fiona Woods for her guidance and patience, and for allowing all the 'eleventh hour' additions in order to provide an up-to-the-minute account of critical events as they unfolded in Kenya and the United States. Sara Barnes, copyeditor extraordinaire, also showed monumental patience and flexibility as we neared the home stretch. Shanmuga Priya and the Macmillan Publishing Solutions team were extremely accommodating as well. I am particularly grateful to my parents, Gary and Christina Richards, who made it possible for me to focus almost entirely on this book over the last year of its creation. My mother (Christina Davidson Richards) also did an outstanding job indexing the book. My colleagues at Working Dogs for Conservation were very understanding, allowing me to finalise the book while juggling new work responsibilities. I would also like to express appreciation to my mentor and colleague Pierre Mineau for his contributions and for giving me the rigorous training and support that such a large undertaking both requires and merits. And, finally, thanks to Iñigo Fajardo, who has helped deepen my understanding of wildlife forensics and confirmed what an effective tool it is in the right hands.

This book is dedicated to all those who are confronting wildlife poisoning, erosion of biodiversity and infringement upon the integrity of our ecosystems, who have acquired indelible knowledge and experiences in the process, and placed themselves and their careers in harm's way by speaking out. I also make a special dedication to griffon vulture C15, whose story is told in Chapter 5, and who epitomises each of the individuals that have succumbed to poisoning. Let the reader assimilate all of their stories, and may their loss not have been in vain.

Contributor Biographies

Ngaio L. Richards

Ngaio Richards is a forensic ecologist and conservationist. Her multidisciplinary background includes a BSc (Hons) in Environmental Science from Acadia University (Nova Scotia, Canada) and an MSc in Natural Resource Sciences with emphasis on applied wildlife biology and ecotoxicology from McGill University (Québec, Canada). Her MSc research, conducted under the direction of Pierre Mineau and David Bird, examined the relative risks posed by habitat loss and pesticide exposure to eastern screech-owls in apple orchards of southern Québec. In autumn 2010, she obtained a PhD in Forensic Science from Anglia Ruskin University (UK) for a study titled: *Detection of nonsteroidal anti-inflammatory drugs in hair, nails and feathers using GC-MS, with emphasis on diclofenac, a forensic tool for wildlife conservation*. Her interests lie in small-scale community-based conservation initiatives and facilitating the development of collaborative environmental monitoring networks. She also has a great fondness for vultures, owls, bears, hyenas and wolves, and is a champion for uncharismatic wildlife. Ngaio is the Canine Field Specialist for Working Dogs for Conservation, a non-profit organisation based in Montana (USA).

CHAPTER 1

Stephen Donovan

Stephen Donovan has been a principal research chemist in the Agrichemical Industry for over 25 years, working for American Cyanamid, BASF and FMC. He obtained a PhD in Organic Chemistry from the University of California and conducted his post-doctoral research at Cornell University. Dr Donovan is the author of numerous publications and patents relating to pesticides. He is proficient with a variety of modern analytical tools such as: LC/MS, LC/MS/MS, GC/MS, ICP/MS and LC/ICP/MS. He also has expertise in organic synthesis, compound purification, compound identification, physical property measurements, quantitative structure activity relationships (QSAR), pharmacokinetics and ADMET (absorption, distribution, metabolism, excretion, and toxicity). He is currently serving as an analytical chemist at the Pennsylvania Department of Health in the Chemical Terrorism Preparedness Section (affiliated with the Centre for Disease Control (CDC)), where he measures toxins in human fluids via LC-MS/MS and LC-ICP/MS.

Mark Taggart

Mark Taggart is an experienced environmental chemist and ecotoxicologist currently working as a research fellow at the Environmental Research Institute in the Highlands of Scotland. He studied as an undergraduate in Liverpool, undertaking a BSc in Earth Science and Countryside Management, and then turned more toward chemistry, carrying out an MSc in Geochemistry at Leeds. He then worked in industry, in flue gas desulphurisation in the two largest coal-fired power stations in the UK, before spending four years with the Environment Agency in London as a Monitoring and Investigations Officer. In 2000, he returned to academia to undertake a PhD in arsenic biogeochemistry at Aberdeen

in Scotland, studying the effects of one of Europe's largest ever acid mine spills at Aznalcóllar in Spain. Since this point, he has undertaken a very wide range of research related to the fate, behaviour and toxicology of organic/inorganic pollutants in the environment in the UK, Spain and India. He has published well over 40-peer reviewed articles and book chapters in this field, many of which are related to the ecotoxicology of heavy metals and metalloids, and the impact of diclofenac (a non-steroidal anti-inflammatory drug) on vultures in India. He has worked extensively within the field of avian ecotoxicology in particular.

CHAPTER 2

Pierre Mineau

Pierre Mineau is a Senior Research Scientist in the Science and Technology Branch of Environment Canada. He is also an Adjunct Professor in the Department of Biology at Carleton University and in the Department of Veterinary Biomedical Sciences at the University of Saskatchewan. He obtained his BSc from McGill University (Québec, Canada) and his MSc and PhD from Queens University (Ontario, Canada). His doctoral research focused on the effects of forestry insecticides on food-caching memory in birds.

For a 15-year period, Dr Mineau was responsible for the wildlife risk assessment of pesticides for the Canadian regulatory system. As part of these responsibilities, he led the scientific review of carbofuran which culminated in the removal of most of its uses from Canada. He received formal commendation for this work. Following a restructuring of this system, he turned to full-time research. With the help of many collaborators, he spans various scales of biological organisation-from the use of sub-cellular biomarkers of pesticide exposure, to analyses of bird population trends in response to pesticide use patterns. By extension, he also studies risk assessment methodology, how agricultural practices affect wildlife and the environment more generally, how to objectively measure and communicate the 'environmental footprint' of pest control practices, as well as the ecological 'value' of birds in cropland. Dr Mineau has authored over 100 peer-reviewed publications and given over 200 presentations. He has served as a consultant in the area of pesticide impacts to several international agencies as well as governmental and non-governmental organisations in Canada and abroad.

Carol Uphoff Meteyer

Carol Meteyer has been a wildlife pathologist at the USGS National Wildlife Health Center (NWHC) in Madison, Wisconsin (USA) since 1992. She received a BSc in Biology and Chemistry at the University of Iowa and worked as a research assistant in Costa Rica on a study of the ecology and feeding habits of *Atta cephalotes* (leaf-cutter ant) in Guanacaste National Forest. She completed a Doctorate in Veterinary Medicine at Iowa State University in 1983. Starting in 1984, Carol conducted a three-year residency in comparative pathology in association with the University of Southern California and the Los Angeles County Medical and Veterinary Service. From 1987 to 1991, she was on the faculty of the UC Davis College of Veterinary Medicine as a diagnostic pathologist with the California Veterinary Diagnostic Laboratory System. She received board certification by the American College of Veterinary Pathologists in 1988.

Carol's duties at the NWHC have both a forensic and diagnostic component. In her capacity as a forensic pathologist, she provides pathology support for legal cases within the US Fish and Wildlife Service Division of Law Enforcement. She has also investigated numerous incidences

of animal poisoning, including carbamate and organophosphate poisoning cases. As a diagnostic pathologist, she is involved in determining the cause of morbidity and mortality in wildlife. Carol has participated in special investigations on migratory birds, endangered species and species of concern, including assessing causes of: southern sea otter (*Enhydra lutris nereis)* population declines, amphibian malformations, vulture (*Gyps* sp.) population declines in Pakistan due to secondary poisoning with the nonsteroidal anti-inflammatory drug diclofenac, the pathology of monkey pox in rodents, pathogenesis of plague in prairie dogs, and the highly pathogenic avian influenza H5N1 in kestrels and shorebirds. Carol has also been part of a team to define pathologic changes associated with diseases in coral and she has served as the lead pathologist at the NWHC investigating white-nose syndrome in bats.

Stuart Porter

Stuart Porter is a Professor of Veterinary Technology at Blue Ridge Community College in Weyers Cave, Virginia (USA). His background includes a BSc in Biology from Washington and Lee University (Virginia) and a VMD from the University of Pennsylvania (Philadelphia). He has worked as a resident veterinarian at the Memphis, Tennessee and Gladys Porter Zoos. In 1982, he co-founded the Wildlife Centre of Virginia (WCV), where he went on to serve as the Director of Veterinary Services for 12 years. It was at the WCV that he documented intoxication in a number of wild birds from carbamates (including carbofuran) and organophosphates, lead and chlorinated hydrocarbons. As a result, he initiated the measurement of cholinesterase levels in various raptors to determine in-house reference ranges. In the process, he discovered that many hawks and eagles admitted as ‘car strikes’ also tested positive for poisoning. He was able to confirm his findings and gather more data by networking with other wildlife professionals across the country. Dr Porter has served on the board of directors of the National Wildlife Rehabilitators Association, the Rachel Carson Council, and the Virginia Veterinary Medical Association. He has given presentations to veterinary students, veterinarians, wildlife rehabilitators and wildlife biologists throughout the US and as far away as Australia to increase awareness of the many man-made toxins and how they affect native wildlife. He has also contributed many articles and book chapters centring on various wildlife-related issues.

CHAPTER 3: KENYA

Joseph O. Lalah

Professor Joseph Lalah has a BSc (Hons) in Chemistry and Biochemistry from the University of Nairobi, an MSc in Energy from the University of Leeds and a PhD in Chemistry from the University of Nairobi. He has worked in various sectors, including government, industry and university. He was a senior lecturer in the Department of Chemistry, Maseno University, before joining the Kenya Polytechnic University College as an Associate Professor in March 2010. Professor Lalah lectures in analytical, inorganic and environmental chemistry. His research area is environmental chemistry and ecotoxicology and he has published several papers in internationally recognised journals. His current research interest is in contaminant residue distribution, fate and impact on the environment and wildlife. He is an alumnus of the British Council Award, the German Academic Exchange Programme (DAAD), the International Atomic Energy Agency and the Alexander von Humboldt Foundation and an affiliate member of IUPAC (Crop Protection Chemistry).

Peter Otieno

Peter Otieno is an environmental research scientist who is keen to study the distribution, fate and contamination of pesticides residues in the environment. He grew up in a village on the shores of Lake Victoria in Kenya, studied at Usenge Primary School and Usenge High School before joining Egerton University in 1992 for a Bachelor of Education, with a major in chemistry. Upon completion, Peter taught chemistry in various secondary schools during which he rose through the ranks to become a Principal. In 2009, he received an MSc in Environmental Chemistry from Maseno University. Mentored by Professor Joseph Lalah, his thesis was titled: *Monitoring carbofuran residues in Laikipia and Isiolo districts for ecological risk assessment*.

The data Peter collected has contributed significantly to the deeper understanding of the potential risks posed by carbofuran residues in the Kenyan environment. Two publications in peer reviewed journals, one using innovative forensic analyses, is a testimony of this contribution. He is currently working on a PhD assessing the influence of climate change on the distribution and contamination of selected carbamates and organophosphate pesticides residues in Lake Naivasha and its biodiversity. This work is partly supported by an International Climate Protection and Resource Conservation Research Fellowship at the Institute of Ecological Chemistry in Munich, Germany.

Martin Odino

Martin Odino is an ecologist with a specialisation in ornithology and a passion for preserving biodiversity. He received a BSc in Zoology from Moi University in 2005 and was affiliated as an intern at the Ornithology Section of the National Museums of Kenya from 2006 to 2007. Through a closely associated committee, the Bird Committee of Nature Kenya, he was assigned to conduct a minor, random survey on the availability, use and regulation of Furadan in Kenya from the end of 2007 into 2008. Based on his findings, he then executed a follow-up study titled: *A selective survey on pastoralist and plantation farming sites for Furadan availability and use as a poison* (2008). Between 2007 and 2008, Martin served as a Species Programme and Advocacy intern with BirdLife African Partnership Secretariat (Kenya) and was involved in another 'mini-survey' which was also conducted jointly with Nature Kenya on: *Availability, use and conservation implication of diclofenac to vultures in Kenya* diclofenac is the veterinary drug responsible for the catastrophic decline of *Gyps* vultures in India).

Periodically, between 2008 to the present, Martin has been affiliated with the Nairobi-based charitable group WildlifeDirect as a consultant in the Campaign to End Wildlife Poisoning. He has also been involved in various projects, both individual and collaborative, mostly ornithological but always relevant to wildlife poisoning: 1) *Measuring the conservation threat to birds in Kenya from pesticide poisoning: a case study of Bunyala Rice Irrigation Scheme* (Funded by Rufford Small Grants (RSG) and detailed in Chapter 3); 2) *Avifaunal and threat status survey in Northern Yala Swamp, Kenya* (Funded by African Bird Club (ABC)); 3) *Assessing the impact of pesticide poisoning on Kenya's big cats and possible alleviation of the situation* (Funded by the National Geographic Society).

Munir Z. Virani

Munir Z. Virani was born and raised in Nairobi, Kenya. He has been associated with The Peregrine Fund (TPF) since 1992, when he was selected to train as a raptor biologist under Simon Thomsett. Munir obtained a PhD in Biological Sciences and Medicine from the University of Leicester (UK) in 2000 and was awarded the Aga Khan Foundation award for excellence in the Field of Science and Technology in 2002. Munir has published over 100 scientific and popular articles including a paper in the esteemed journal *Nature*. In 2007, he was awarded a prize for the Wildlife Photographer of the

Year in a competition organised by *Twende Travel Magazine*. He currently heads TPF's Africa and South Asian Raptor Conservation Programs. His research has focused on Augur buzzards, African fish eagles, Sokoke scops owls, and, more recently, on *Gyps* vultures (investigating the catastrophic population decline in the species that was triggered by the use of the nonsteroidal anti-inflammatory drug diclofenac to treat livestock on the Asian subcontinent).

Darcy Ogada

Darcy Ogada is a wildlife conservationist who specialises in the ecology and conservation of African raptors. In 2008, she was awarded a PhD in Zoology from Rhodes University (South Africa) for a study titled: *The ecology and conservation of Mackinder's eagle owls (Bubo capensis mackinderi) in central Kenya in relation to agricultural land-use and cultural attitudes.* She received an MSc in Biology from the State University of New York at Albany (USA) in 2002 for research that examined the impacts of large ungulates on bird populations in an East African savannah. Dr Ogada currently works as Assistant Director of Africa Programs for The Peregrine Fund and is based in Kenya. She also chairs the Raptor Working Group of Nature Kenya. Actively involved in the campaign to stop wildlife poisoning in Kenya since 2007, Darcy has authored a number of reports and papers which are referenced in Chapter 3, one of which, on the issue of Furadan use to poison wildlife species, catalysed stakeholders into action again.

Laurence Frank

Laurence G. Frank has a BA from Reed College (Oregon, US), an MSc from the University of Aberdeen (UK), and a PhD from the University of California at Berkeley (US). He has been a research scientist at Berkeley since 1984, first as part of the Berkeley Hyena Project and currently in the Museum of Vertebrate Zoology. After spending 20 years studying the behavioural ecology and endocrinology of the spotted hyena (*Crocuta crocuta*), he turned to conservation research and is now affiliated with Panthera. Laurence directs the *Living with Lions* programme in Kenya, which uses a multidisciplinary approach to the conservation and management of lions and other large African predators outside protected areas.

Alayne H. Cotterill

Alayne Cotterill has worked with large carnivores in Africa since 1993, when she carried out the first cost-benefit analysis for including lions in the growing private wildlife reserves in southern Africa as part of her MSc. Over the last 18 years, she has developed extensive experience on the issue of large carnivore/human conflict in southern and eastern Africa, and has spent the last seven years as a biologist with the *Living with Lions* programme in Kenya. Alayne is also the recipient of two Panthera Kaplan Graduate Awards. She is currently carrying out a DPhil with Oxford University's Wildlife Conservation Research Unit, investigating how conflict with humans affects lion behavioural ecology and demography.

Stephanie Dolrenry

Stephanie Dolrenry is a field biologist who has spent the past 15 years in a variety of biomes, across the US, the Bahamas, Hawaii and, for the past six years, Kenyan Maasailand. Her research in Kenya

focuses on the behavioural ecology of large carnivores, namely lions and spotted hyenas, living in human and livestock-dominated areas. She is interested in the development and implementation of non-invasive and local knowledge-based monitoring techniques to study behaviours and mitigate conflicts of elusive and persecuted carnivore populations. Stephanie is the Director of Carnivore Biology for the Lion Guardians programme. She has a Wildlife Conservation and Management degree from Missouri State University and is currently completing her PhD at the University of Wisconsin-Madison as part of the Carnivore Coexistence Lab. Stephanie's research is funded through a National Science Foundation Graduate Fellowship and she has twice been a recipient of a Panthera Kaplan Graduate Award.

Leela Hazzah

Leela Hazzah has a BSc in Biology from Denison University and an MSc from the University of Wisconsin-Madison, where she is also completing her PhD. She has worked on conservation issues in East Africa for 12 years, spending half of this time working with *Living with Lions*. Leela's research interest is in designing co-management frameworks, specifically using cultural and traditional values to initiate conservation programmes and mitigate livestock-carnivore conflict. Leela currently directs the Lion Guardians programme, a community conservation initiative which provides a platform for Maasai warriors to engage with and participate in lion conservation. Leela has been awarded a Fulbright Hays Doctoral Fellowship, four Panthera Kaplan Graduate Awards, a Fellowship from Wings WorldQuest, and a Jordan Prize for African Studies.

Dino Martins

Dino J. Martins, a conservationist and biologist, completed a PhD at Harvard University in 2011 that focused on the interactions of insects and plants, specifically those between ants and acacias in relation to external species and how they influence/exploit mutualisms. Dino also holds an MSc in Botany from the University of Kwa Zulu Natal, South Africa, and a BA in Anthropology (with distinction) from Indiana University (USA). Dino has published numerous articles in scientific, natural history, and environmental magazines. He is currently the Chair of the Insect Committee for Nature Kenya and The East Africa Natural History Society.

Dino has taught courses and led expeditions in Africa for the Kenya Museum Society, Princeton University, Georgetown University and Stony Brook University. A recipient of the Derek Bok Teaching Award and the Ashford Fellowship in the Natural Sciences from Harvard University, he also held the Smithsonian Institution Fellowship in 2004, and was awarded the 2002 and 2003 Peter Jenkins Award for Excellence in African Environmental Journalism. In 2009, he won the Whitley Award for Conservation – one of the most prestigious global conservation prizes – called the 'Green Oscar'. This was for his work on pollinator conservation in Kenya, which is detailed in Chapter 3. In May 2011 Dino was named an Emerging Explorer by National Geographic.

CHAPTER 4: INDIA

Venkataramanan Ragothaman and Sreekumar Chirukandoth

Dr V. Ragothaman (MVSc) an animal geneticist, is presently working as Assistant Professor at the Sheep Breeding Research Station (SBRS), Tamil Nadu Veterinary and Animal Sciences University

(TANUVAS), Sandynallah, The Nilgiris. He had earlier served in Nilgiris as a Veterinary Assistant Surgeon for six years in the Animal Husbandry Department of Tamil Nadu, and has extensive working knowledge of the area. He is also a wildlife enthusiast and actively participates in wildlife-related endeavours. Dr S. Chirukandoth has a doctorate in Veterinary Parasitology and, after a brief stint with the State Animal Husbandry Department as a Veterinary Assistant Surgeon, joined TANUVAS in 1994. He is currently working as an Associate Professor in the SBRS. He is a self-taught herpetologist and is actively involved in the conservation of venomous snakes.

The Nilgiris Biosphere Reserve was the first Biosphere Reserve established in India and includes several national parks, tiger reserves and wildlife sanctuaries. Both Drs Ragothaman and Chirukandoth have been involved in wildlife rescues and have performed necropsies on a variety of wildlife species, including those intentionally poisoned with a number of compounds. As practicing veterinarians, they have treated several cases of poisoning in domestic cattle using pesticides, including carbofuran, within the region. They have also documented several incidences of carbofuran poisonings in peer-reviewed journals (referenced in Chapter 4).

CHAPTER 5: THE EUROPEAN UNION AND OTHER PARTS OF EUROPE

Jitka Větrovcová

Jitka Větrovcová is a biologist and conservationist currently at the Agency for Nature Conservation and Landscape Protection of the Czech Republic, where she coordinates the implementation and preparation of country-wide Action Plans and Management Plans for endangered animal species. She obtained a BSc in Environmental Biology and an MSc in General Biology from the University of Texas at Arlington. Her thesis focused on monitoring methods for Eurasian otters (*Lutra lutra*).

Kateřina Poledníková

Kateřina Poledníková obtained an MSc in Systematic Biology and Ecology from the Palacky University in Olomouc. Her thesis focused on the pied flycatcher (*Ficedula hypoleuca*). Since then, she has worked on various research projects focusing on Eurasian otter as well as American and European mink (*Mustelidae*), both in the Czech Republic and abroad. In 2007, she established the NGO ALKA Wildlife and is currently involved as a director and scientific researcher there.

Lukáš Poledník

Lukáš Poledník obtained an MSc in Systematic Biology and Ecology from Palacky University in Olomouc. His thesis focused on the marking behaviour of the Eurasian otter. In 2005, he completed a PhD at the same university. He has led/participated in various scientific projects on otters, American and European mink and recently joined the NGO ALKA Wildlife. Dr Poledník coordinates otter monitoring efforts within the Czech Republic and is a member of the IUCN Otter Specialist Group.

Hugh Jansman

Hugh Jansman is an animal ecologist. From 1992 to 1998, he studied Biomedical Science within the Medical Department of Leiden University (Netherlands). During the final stage of his studies he

focused on wildlife health, specialising in necropsies and the effects of toxic substances on animal populations. Since then, he has worked for Alterra, a research institute affiliated with Wageningen University, which is involved in the conservation (and sometimes re-introduction) of species such as otter, black grouse, wild boar, red deer, meadow birds, geese, birds of prey, predators, reptiles and amphibians. Dr Jansman uses molecular tools to carry out both non-invasive and more conventional forms of monitoring. He also conducts necropsies and is involved in telemetry work. He is often consulted by law enforcement groups on matters related to species determination and the use of conservation genetics (e.g., kinship determination). Dr Jansman is the chairman of the Dutch working group on pine martens (www.werkgroepboommarter.nl) and a board member of the Dutch Mammal Society (www.zoogdiervereniging.nl).

Peter van Tulden

Peter van Tulden has worked in the field of wildlife forensics since October 2009. His multidisciplinary background is based on a study of medical biology at the Higher Laboratory School (in Delft, Holland). After finishing his schooling, he initiated work on isotype-specific ELISAs for bovine herpes virus (Type 1) antibodies in Lelystad, Holland. He was an analyst at the National Fish Disease Laboratory (also in Lelystad) for three years. From 2002 until 2009, he served as the Head of the Dispatching Service Unit of the Central Veterinary Institute (Lelystad), where he is currently acting as the Wildlife Research Coordinator. His interests lie in birds, especially birds of prey.

Hermann Ammer

Hermann Ammer is a veterinarian who graduated from the University of Munich (Germany) in 1986. After working in a mixed large and companion animal practice, he moved back to the university in 1990 to carry out a PhD in Pharmacology and Toxicology. He has been a Professor of Clinical Pharmacology in the Department of Veterinary Sciences at the University of Munich since 2002. He is especially interested in the cellular and molecular mechanisms of adverse drug reactions and is currently establishing a pharmacovigilance centre for the southern region of Germany. He runs an analytical laboratory unit for drug monitoring and the detection of common animal poisonings, offering this service to veterinary surgeons in southern Germany, Austria and Switzerland to help them with diagnosis and therapy of intoxications.

Christian Pichler

Christian Pichler is an ecologist and conservationist. He studied Biology at the University of Vienna (with emphasis on ecology and specialisation in limnology). His MSc research, conducted at the same university, under the direction of Friedrich Schiemer, examined the ecology of the fishes of Quebrada Negra, a first order neotropical lowland stream in Costa Rica. Christian began working for WWF Austria in 2006, immediately after completing his studies. Since then, he has been part of the National Programme, within the Department of Natural Conservation. At present, he is mainly responsible for the conservation of large carnivores in Austria (especially white-tailed eagle, brown bear, Eurasian lynx and grey wolf). The ultimate goal is to have viable bear, lynx, wolf and white-tailed eagle populations in Austria, in the sense of their having a favourable conservation status and being connected with other populations, while ensuring an administrative framework and adequate legislation to proactively manage conflicts with human interests.

Iñigo Fajardo

Iñigo Fajardo has a PhD in Biology and an MSc in Environmental Management. He has devoted much of his time to the management and conservation of highly threatened Iberian species, and has been involved in similar endeavours in other countries including Argentina, Perú, South Africa, Zimbabwe, Uganda, the United Kingdom, Norway and Malaysia. He trained as a marine mammal medic (British Diver's Marine Life Rescue) and lectures on a number of topics including wildlife management and forensic techniques. Since 2000, he has served as an advisor on wildlife matters for the Government of Andalucía. His areas of specialisation are applied forensics and prosecution of crimes against wildlife.

Irene Zorrilla

Irene Zorrilla has a PhD in Biological Sciences from the University of Málaga (Spain) and has written a second doctoral thesis in veterinary medicine (University of Murcia). For 11 years, she was involved in research and teaching in the departments of Microbiology of the Faculty of Sciences of the University of Málaga, the University of Santiago de Compostela and the University of Valencia (UV, Spain). She has also served as the Technical Director of the Andalucían Institute of Pathology and Microbiology of Málaga (IAMA). Irene is currently Head of Laboratory at the Centro de Análisis y Diagnóstico de la Fauna Silvestre (Centre for Analysis and Diagnosis of Wildlife) for the Ministry of Environment of Andalucía.

Antonio Ruiz

Antonio Ruiz has a BSc in Biological Sciences. He is part of the antipoisoning project: Estrategia de Control de Venenos y otras Amenazas para la Fauna Catalogada for the Consejería de Medio Ambiente. Antonio has coordinated field assistants on the ground for the control of poisoning in Andalucía since 2004. He specialises in the investigation of poisoning, the coordination of police forces and the execution/implementation of antipoisoning measures. Antonio currently designs and manages the strategic use of canine units for the region and oversees the database of poisoning incidents managed by the government.

Isabel Fernández

Isabel Fernández is a veterinarian who graduated from the Complutense University of Madrid (Spain) in 2004. She then completed a series of internships to broaden her knowledge in equine medicine and reproduction, and to widen her experience in exotic/wild animal medicine and management (e.g., Aznalcóllar Equine Hospital (Seville), Zoo-Aquarium (Madrid), Foundation for the Preservation and Recovery of Marine Animals (Barcelona). Isabel is currently head of the veterinary branch of the Centro de Análisis y Diagnóstico de la Fauna Silvestre) for the Ministry of Environment of Andalucía.

Antonio Valero, Ernesto Sáez, F.M. Molino and Jesús Olivares

Antonio Valero (BSc in Biological Sciences), Ernesto Sáez, F.M. Molino and Jesús Olivares have served as field assistants in western and eastern Andalucía since 2004. They are all part of the antipoisoning project: Estrategia de Control de Venenos y otras Amenazas para la Fauna Catalogada. Together, they are the beating heart of the project, speaking directly to farmers, shepherds,

landowners and hunters, among others and disseminating valuable information to stakeholders. They also attend all dog inspections and assess the police in their investigative techniques and procedures.

Péter Bedö

Péter Bedö is a farming/agricultural trade journalist and part-time naturalist in Hungary. He has an MSc in Agricultural Sciences (with a specialisation in Wildlife Management) and his thesis focused on population changes in rook and crow populations in Hungary. He has participated in field-based conservation projects in Hungary since 2001, mostly monitoring raptors and studying large carnivores. In the autumn of 2004, Péter interned at Hawk Mountain Sanctuary (Pennsylvania, USA), where his tasks ranged from guiding visitors to mapping migratory patterns using GIS applications. Since 2005, he has worked as a writer for a trade magazine while focusing increasingly on large carnivore monitoring. Besides tracking lynx in the northern hills of Hungary, he has, since 2010, been working with an NGO based in Slovakia on a project that aims to increase the available data about large carnivores, primarily using volunteers to gather the information.

Gordana Pavokovic

Since childhood, Gordana Pavokovic has been interested in animals and their conservation. The war in Croatia prevented her from studying at the Veterinary University in Zagreb and she chose instead to study as a health inspector at the University of Rijeka in the Medical Faculty (1991–1995). But her love of nature directed her again towards studies in natural sciences and she went on to complete an MSc in Ecology at the University of Zagreb in the Faculty of Science in 1998. She wanted to work on a project that would help animals and became involved in the issue of illegal poisoning of Eurasian griffon vultures on the Kvarner Islands in the northern Adriatic. Her thesis was titled: *Population viability analysis of Eurasian griffon (Gyps fulvus) in Croatia*. Many griffons brought to the Vulture Recovery Centre on the Island of Cres, where she worked for a time, suffered from neurological symptoms, accompanied by vomiting and diarrhoea (all characteristic of exposure to organophosphorus and carbamate pesticides), which usually ended with the death of the bird. After seeing this so much firsthand, she decided to pursue the use of these compounds as poisoning agents. Due to her dedicated work with griffon vultures, she was elected vice president of the Eurasian Griffon Vulture Working Group in 2005. She is presently working as a teacher of biology.

CHAPTER 6: THE UNITED KINGDOM AND THE REPUBLIC OF IRELAND

Ruth Tingay

Ruth Tingay is a British-based ornithologist with field experience from North and Central America, Europe, Africa, the Middle East, Central Asia and South East Asia. She studied the critically endangered Madagascar fish eagle for an MSc (2000) and PhD (2005) with The Peregrine Fund at the University of Nottingham, UK. In addition to her studies in Madagascar, other research has included Mauritius kestrels and echo parakeets (Indian Ocean), raptor migration (USA, Israel and Mexico), American kestrels (USA), white-tailed sea eagles, golden eagles, goshawks, hen harriers, red kites, whooper swans and golden plover (Scotland), grey-headed fish eagles (Cambodia), and Pallas' fish eagles, white-naped cranes, whooper swans and bar-headed geese (Mongolia).

Ruth is a member of the Scottish Raptor Study Group, the Eagle Conservation Alliance, the Asian Raptor Research and Conservation Network and the African Raptor Network. She is a research associate at Hawk Mountain Sanctuary (USA) and the Percy Fitzpatrick Institute of African Ornithology (South Africa) and has worked as an associate with the Wildlife Conservation Society (Cambodia and Mongolia). Ruth serves on the Review Board of the European Science Foundation and served two terms as an International Director of the Raptor Research Foundation (2004–2008); she is currently serving as President (2009–2013). Her first book, *The Eagle Watchers: Observing and Conserving Raptors around the World* was published in 2010 by Cornell University Press.

Douglas McAdam

Douglas McAdam is the Chief Executive of the Scottish Rural Property and Business Association (SRPBA). The SRPBA represents the interests of land owners, estates, farmers and diversified rural land-based businesses across Scotland. Prior to joining the SRPBA as CEO in October 2006, Doug had an international career in the commercial sector in the Far East and Europe, working at senior and director level for companies including: The Swire Group, Cathay Pacific Airways Ltd, Kelvin International Services & Primary Management Ltd (a part of the Sodexho Group), and Thames Water. He received an MSc (Hons) in Geography from the University of St Andrews (Scotland). A resident of Highland Perthshire, his passions are deer stalking and management, fly fishing and field sports, classic Land Rovers and mountain biking.

Michael J Taylor

Mike Taylor (BSc, PhD, CChem.) is Head of Chemistry at Science and Advice for Scottish Agriculture (SASA), an Edinburgh-based scientific division of the Scottish Government. SASA Chemistry Branch provides a variety of analytical chemistry services and expert advice in support of the Scottish Government's participation in UK and EU annual surveillance programmes that monitor the impact of pesticide use on food and drink, animals and honeybees. The unit also provides essential support to law enforcement agencies and NGOs investigating suspected (illegal) animal poisoning activities. Mike's current appointment followed an extensive career in industry and the commercial sector where he used a wide range of mass spectrometric and chromatographic techniques in novel applications as a Senior Research Scientist (ICI Materials Science Group), Analytical Services Technical Manager (Enron Teesside Operations Ltd) and European Applications and Demonstration Laboratory Manager (Waters Corporation). Mike received his PhD from the University of Wales – Swansea in 1995 for research on '*Field Desorption Mass Spectrometry Applied to Polymers and Compounds Relevant to their Synthesis*'. This was achieved while working full time at ICI and under the academic supervision of Professor Dai Games. Mike has authored and co-authored several peer-reviewed papers and contributed to the scientific programme of numerous national and international scientific meetings throughout his career.

CHAPTER 7: LATIN AMERICA

Alexandre de Almeida

Alexandre de Almeida holds a degree in Biological Sciences from the Universidade Estadual Paulista 'Júlio de Mesquita Filho' (1997), an MSc in Forestry Resources (2001) and a PhD in Applied Ecology

(2006), both from the University of São Paulo. He also completed post-doctoral work in Zoology at the Federal University of Bahia (2010). Alexandre has worked in environmental consulting enterprises, forestry companies, federal government, nongovernmental organisations, research and teaching. His areas of interest include biological conservation, ecology (birds and mammals) and management of environmental impacts. He is currently a Professor in the Department of Environmental Resources of the National Service of Industry (SENAI-CETIND) in Lauro de Freitas, Bahia.

Álvaro Fernando de Almeida

Álvaro Fernando de Almeida received a degree in Biological Sciences from the University of Mogi das Cruzes (1972) and a PhD in Biological Sciences (Zoology) from the University of São Paulo (1982). He was a Professor in the Department of Forestry Science, University of São Paulo since 1979, acting in the Wildlife Management, Biological Conservation and Management of Environmental Impacts. Álvaro retired in 2003, but continued teaching until 2010. He is currently a consultant and a happy farmer.

CHAPTER 8: THE UNITED STATES AND CANADA

Linda Lyons

Linda Lyon received BA and MSc degrees from Rutgers College and Rutgers University, respectively (New Jersey, USA). She has worked for the United States Departments of Energy, Commerce, Agriculture, and Interior and the Environmental Protection Agency (EPA). While at EPA, Linda's assignments included principal ecologist for the Special Review of carbofuran. In 1991, she transferred to the Fish and Wildlife Service (FWS) where she served as the Coordinator for Integrated Pest Management. Responsibilities included oversight of FWS pesticide use; Endangered Species Act consultations for pesticides; legal investigations concerning wildlife die-offs caused by pesticides; and instructing on courses such as *Pesticide Effects to Fish and Wildlife Resources*, *Environmental Crimes Investigations*, and *Environmental Toxicology*. She has taught for the Federal Law Enforcement Training Centres at Marana (Arizona), and Glynco (Georgia); Environmental Protection Agency; National Park Service; Department of Defense; US Forest Service National Advanced Resource Technology Centre; and several state agencies. Since 1997, Linda has been the Environmental Contaminants Coordinator for the National Wildlife Refuge System. Duties involve issues such as oil spill response, contaminant cleanup, contaminant investigations, oil and gas production, and Superfund-related actions. Linda maintains credentials as a Certified Pesticide Applicator, Hazardous Materials Responder and Emergency Medical Technician.

Stella McMillin

Stella McMillin is an environmental scientist with the California Department of Fish and Game, where she investigates pesticide-related fish and wildlife losses in the State of California. Her current research includes monitoring anticoagulant rodenticides in non-target wildlife, mostly as a result of secondary exposure. One of her responsibilities is to review pesticide registration information for potential hazards to wildlife in the State. Ms McMillin is also involved in educating pesticide applicators about wildlife issues and participates in environmental education of elementary school students. She received a BSc and MSc in Biological Sciences from California State University in San Luis Obispo, California.

1 An overview of the chemistry, manufacture, environmental fate and detection of carbofuran

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1.1 Introduction

The aim of this chapter is to provide the reader with a comprehensive understanding of carbofuran as a compound and a familiarity with the technical terms used throughout this book. First, we outline the features which differentiate carbofuran from other compounds and detail its chemical properties. We then summarise its environmental fate, in other words what happens to it once it is in the environment, and conclude with a discussion of the most common methods of analysing and detecting carbofuran in environmental samples.

1.2 The chemistry and mode of action of carbofuran

Carbofuran is an organic compound (meaning that it is made up of a carbon skeleton), composed of a benzofuranyl component which is connected to a carbamate group (circled in Figure 1.1), i.e., derived from carbamic acid. Its molecular formula is denoted as $C_{12}H_{15}NO_3$ and its chemical name is: 2,3-dihydro-2,2-dimethyl-7-benzofuranyl *N*-methylcarbamate. Carbofuran is a systemic insecticide,

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Edited by Ngaio Richards.

which means that when it is applied it enters into a plant, is transported by the sap, and when insects or other pests feed on other parts of the plant, they become poisoned.

The chemical structure of carbofuran is shown in Figure 1.1. As a group, carbamates can be classified into N-methyl carbamates of phenols (e.g., carbofuran, carbaryl (Figure 1.5) and propoxur) and the N-methyl carbamates of oximes (e.g., aldicarb and methomyl). These carbamates can be synthesised from the reaction of methyl isocyanate with the hydroxyl group of phenols and oximes. The biological activity of these carbamates comes from their ability to essentially liberate methyl isocyanate (MIC) inside the organism. Methyl isocyanate is quite reactive (i.e., toxic) and binds to enzymes that have reactive sulfhydro (RSH) and hydroxy (OH) groups. Since the activity of enzymes often relies on such groups repeatedly making and breaking bonds many thousand of times a second, the enzymes become inactive (inhibited). MIC is the industrial compound that was released into the air in 1984 in Bhopal (India) and caused the death of between 3 000 and 15 000 people and injured over half a million people (see also Chapter 4).

Other important pesticide groups include the organophosphorus pesticides (e.g., monocrotophos (Figure 1.6), dimethoate, diazinon and phosalone), and the organochlorines (e.g., DDT (Figure 1.7), aldrin, its metabolite dieldrin (Figure 1.8), and endrin), often abbreviated as ‘OP/OPCs’ or ‘OCs’, respectively. Carbamates (often abbreviated as ‘CMs’ or ‘CBs’) and organophosphorus compounds both have a non-discriminate (or broad-spectrum) mode of action, i.e., one that inhibits cholinesterase enzyme activity in insects, mammals and birds. For this reason they are sometimes referred to as ‘anti-cholinesterases’. Involved in virtually all physiological responses and mechanisms, no other enzyme is thought to perform such a complex or extensive set of functions within the animal kingdom. The mechanism by which cholinesterase inhibition occurs and its clinical impact on avian and mammalian wildlife, are further detailed in Chapter 2, which also discusses relevant diagnostic and rehabilitation measures.

It is this broad spectrum of activity that also makes carbofuran an ideal insecticide, acaricide (against ticks and mites) and nematicide (against nematodes). Plant protection products containing carbofuran as the active ingredient (often denoted as ‘ai’ or ‘AI’) have been used worldwide to control pests in sugarcane, sugar beet, maize, coffee and rice crops. Carbofuran is available in liquid, silica-based granular and corncob formulations (further discussed in Chapter 8). Sand, clay or granulated dried corncob formulations are intended to enable the active ingredient to be released more slowly into the rhizosphere, the zone immediately surrounding the roots of a developing plant.

As such, carbofuran is particularly effective in controlling rice pests such as green leafhoppers (*Nephotettix virescens*), brown plant hoppers (*Nilaparvata lugens*) and more generally, stem borers and whorl maggots. This is because leaf hoppers and plant hoppers are piercing-sucking phloem feeders, and carbofuran is phloem systemic and therefore available in the phloem sap. Other pests, even if resistant to organophosphorus insecticides (e.g., white flies, leaf miners, ants, scale insects, cockroaches, wasps and aphids), can be effectively controlled by carbofuran. Although both organophosphates and carbamates have the same mode of action, different organisms can be resistant to one class of compound but not necessarily resistant to the other.

Unfortunately, for reasons which remain unclear, birds in particular are simply not equipped to detoxify (or effectively metabolise) either carbamate or organophosphorus compounds before succumbing to their toxic effect (Mineau 2009). Consequently, such ‘general biocides’ are now increasingly viewed as ‘old-fashioned’ and, as such, are very slowly being phased out and replaced by new compounds that *do* discriminate between target insects and non-target organisms or wildlife. Such compounds are therefore inherently less ‘ecotoxic’, but may still have significant unintended impacts on beneficial non-target insects, among others. For example, imidacloprid, a nicotinic systemic insecticide, was introduced as a ‘less toxic’ replacement. While not very toxic to animals in general (see www.pesticidemanual.com/ and http://www.beekeeping.com/articles/us/imidacloprid_bayer.htm), studies have indicated that exposure to sublethal levels slows mobility and communication capacity in honeybees (e.g., Medrzycki, Montanari, Bortolotti et al. 2003).

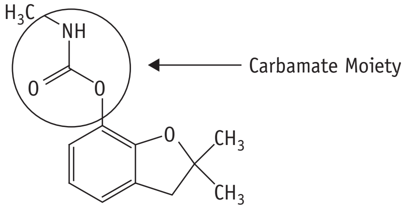

Figure 1.1 Chemical structure of carbofuran

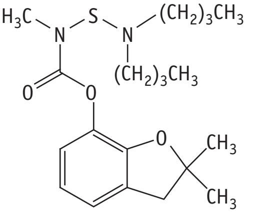

Figure 1.2 Chemical structure of carbosulfan

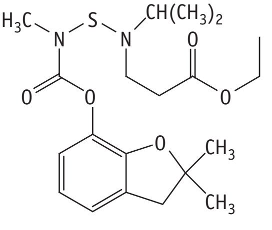

Figure 1.3 Chemical structure of benfuracarb

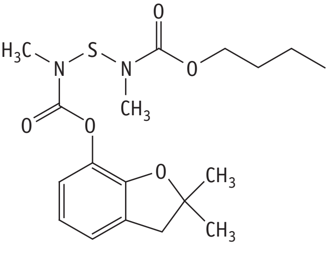

Figure 1.4 Chemical structure of furathiocarb

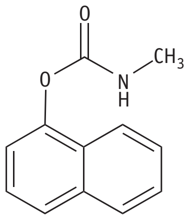

Figure 1.5 Chemical structure of carbaryl

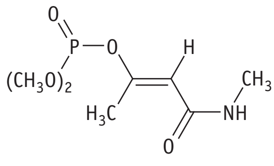

Figure 1.6 Chemical structure of monocrotophos

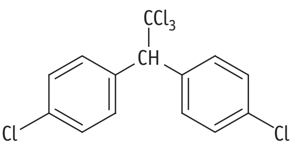

Figure 1.7 Chemical structure of DDT

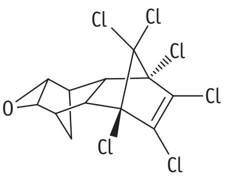

Figure 1.8 Chemical structure of dieldrin

1.3 Manufacture and formulation of carbofuran

Carbofuran was developed in the 1960s, patented in 1965 (Budavari 1989), and introduced on the market as a systemic and broad spectrum nematicide in 1967 under the well-known brand/trade name of Furadan by FMC (Farm Machinery Corporation), based in Philadelphia in the United States (http://www.fmc.com/AboutFMC/CorporateOverview/FMCHistory.aspx?PageContentID=9). In some parts of this book (especially Chapter 3, regarding the situation in Kenya), the 'names' carbofuran and Furadan are effectively used interchangeably. This simply reflects the fact that in certain countries carbofuran (i.e., the product name) is more commonly known by its trade/brand name (in this case, Furadan). Each formulation is named according to its percentage active ingredient, i.e., the amount of carbofuran (by weight) in the formulation. Hence, Furadan 3G, 10G, and 15G contain 3, 10 and 15% (w/w, i.e., weight by weight or wet weight) of the active ingredient, respectively.

FMC held sole patent from the 1960s and is still considered the major global manufacturer of carbofuran. Patent law is country-specific, and we were unable to specifically determine when FMC's original patent would have expired (i.e., when generic formulations would have been permitted).

Table 1.1 Name and headquarter location of selected companies that manufacture carbofuran products and trade names under which they are sold

Company name	Headquarter location	Trade name
Agro-Chemie	Hungary	Chinufur
Aimco Pesticides Limited	India	Furacarb
Cequisa	Spain	Cekufuran
Makhteshim Agan Industries	Israel	Carbodan
Nagajura Agridar	India	Fury
Sanachem (Pty) Ltd	South Africa	Terrafuran
Sipcam	Italy	Carbosip, Rampart
Sanonda/Zhengzhou Pesticides Co Ltd.	China	Agrofuran

Information taken from The Pesticide Manual (www.pesticidemanual.com/)

However, in the United States, patents are granted for a maximum of 20 years, and Chapters 5 and 6, for example, list other manufacturers as registrants of the product in the late 1980s, which leads us to believe that FMC's sole patent expired sometime in the mid to late 1980s. Table 1.1 lists other known manufacturers of carbofuran around the world. For a complete list of manufacturers of carbofuran products, the reader is referred to the Pesticide Manual (www.pesticidemanual.com/).

1.4 Carbofuran in the environment

The dominant source of carbofuran emission to the environment is via its application as an insecticide. In this context, it is sobering to consider that, in general, approximately 90% of all agricultural pesticide applications never actually reach their target organism(s). This 'excess' is instead widely dispersed into the environment, entering the air, soil and water (Moses, Johnson and Auger 1993). The environmental fate and persistence of any specific compound is also governed by the prevailing climate and as such differs between tropical and temperate regions (Fodor-Csorba 1998). Elevated temperatures can lead to pesticide loss and deterioration through volatilisation (i.e., transformation to a gas and then dissipation) and increased microbial activity. Sunlight and ultraviolet (UV) intensity is also greater in tropical and subtropical regions, which again can lead to more rapid photodegradation (Fodor-Csorba 1998). Such degradation and the reaction products formed (some of which may be more toxic than the original parent compound) are then themselves transported into the environment. The ability to identify and analyse such degradation products and metabolites is likely to become increasingly important in the future as 'sustainable' biocide products with low ecotoxicity are identified and developed.

In soil, chemical transformation processes are influenced by factors such as pH, temperature, clay content, organic matter content, moisture content, the presence of micro-organisms, and the types of functional groups that are attached to the pesticide molecule (Lalah, Kaigwara, Getenga et al. 2001). Chemical reactions can be catalysed by clay surfaces, metal oxides and metal ions in soil. Likewise, the rate of chemical hydrolysis (i.e., the addition of water to a compound) occurs more rapidly in alkaline soils than in neutral or acidic soils (Lalah, Kaigwara, Getenga et al. 2001). As such, carbofuran tends to be more stable in acidic soils. Soil pH is indeed one of the major determinants of pesticide persistence (see Section 3.2, Chapter 3). In addition, external environmental factors such as wind, humidity, soil and air temperature, as well as rainfall, all influence the degradation and

dissipation of all pesticides within soil (Lalah, Kaigwara, Getenga et al. 2001). The behaviour and fate of carbofuran in tropical soils is also further outlined in Chapter 3 (Kenya).

Carbofuran is relatively soluble in water and so has the potential to contaminate a variety of aquatic resources, including groundwater. Surface water may be compromised via improper disposal, accidental spillages and direct contamination. The latter is most likely when sprays are being applied but will also occur via run-off of surface and drainage water from fields where crops or soil are treated (Helmut 1990). Field flooding following adverse weather or as an agricultural practice has also resulted in carbofuran-related mortality of non-target organisms such as birds. Various studies conducted by the Canadian Wildlife Service (among others) are extensively reviewed by P. Mineau and colleagues in Chapter 8. These indicate that this problem is severe in heavy acidic soils where carbofuran is known to have a much longer half-life (Mineau 2009).

1.4.1 Carbofuran precursors, metabolism and degradation products

In addition to the pesticide applied, it is essential to monitor its active metabolites and degradation products (Fodor-Csorba 1998). Firstly, because degradation products may indicate an application has occurred, but secondly, because such products may themselves be highly ecotoxicologically relevant. In flooded and non-flooded soils, carbofuran metabolises to carbofuran phenol, 3-hydroxycarbofuran and 3-ketocarbofuran (the three principle metabolites), and to 3-ketocarbofuran phenol and 3-hydroxycarbofuran phenol (as shown in Figure 1.9). Given that the carbamate group is involved in the inhibition of cholinesterase, the metabolites which retain this group (i.e., 3-hydroxycarbofuran and 3-ketocarbofuran) are likely to be just as toxic as carbofuran itself. The various phenol derivatives, which have lost the carbamate group, are consequently not as toxic, if toxic at all.

However, identifying the presence of carbofuran (or its metabolites) in a sample must be considered in light of the presence or absence of other compounds whose degradation products may include carbofuran (and/or its metabolites). For example, carbosulfan (see Figures 1.2 and 1.10) is another carbamate insecticide which has the same core structure as carbofuran, namely hydroxybenzofuran (the same metabolite can be formed from either of these carbamates). As previously mentioned, the core structure is generally considered to be non-toxic, but the carbamate group is reactive. When the nitrogen-sulfur bond of carbosulfan is broken, carbofuran is formed. The liberated dibutylaminothio group on the carbosulfan (circled in Figure 1.10) is called a *pro*-group, meaning that it can liberate the parent compound (carbofuran) by oxidation *in vivo*.

Since such reactions can occur, analyses for carbofuran and/or its metabolites could test positive even if the actual products applied contained carbosulfan or other structurally similar compounds such as benfuracarb (Figure 1.3) and furathiocarb (Figure 1.4) as the active ingredient. When the use of all such structurally similar compounds is illegal, and the principle reason for analysis is simply to ascertain whether or not poisoning was the cause of death, this is obviously less of an issue. However, when the use of several compounds is permitted, or one or several are known to be used illegally, specific identification/implication of a compound may prove very important from a legal perspective.

Interestingly, despite the similarity in their chemical structures, carbosulfan (widely known under the FMC trade/brand name Marshal), differs from carbofuran in terms of its physical properties. Carbosulfan is not as soluble in water and has a lower vapour pressure (approximately 3000 times less, and 57% lower (both at 25°C) respectively). Consequently, carbosulfan is actually less prone than carbofuran to wash off or evaporate from foliar surfaces, and as such it is actually more effective against soil dwelling insects and nematodes (www.pesticidemanual.com/).

One way to differentiate (analytically) between carbofuran and other structurally similar carbamates might be to add a nontoxic marker at manufacture. Since this implies an extra manufacturing cost, this is perhaps unlikely to happen, but it certainly could be considered. When working with carbamates and their fate, behaviour and effects in the environment, and where information suggests

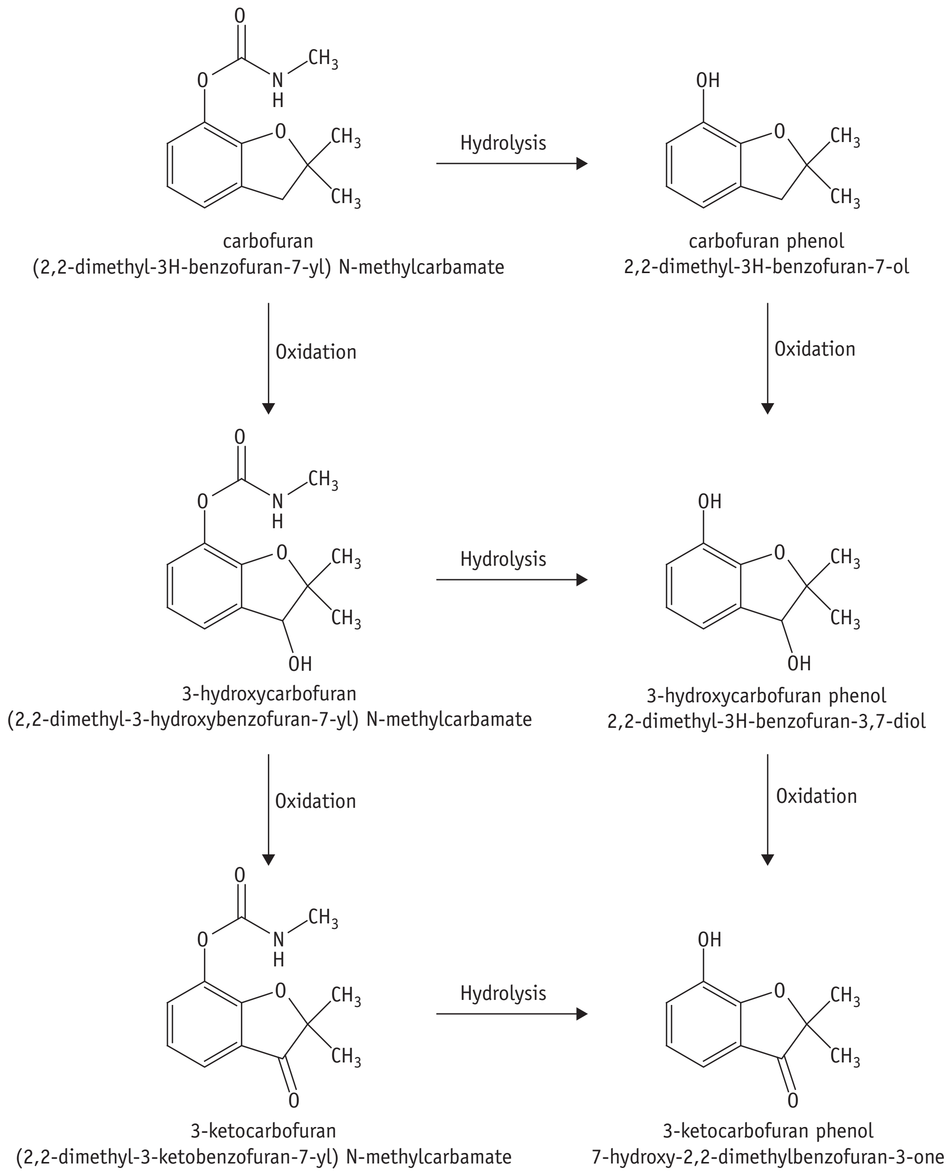

Figure 1.9 Degradation of carbofuran to metabolites by oxidation and hydrolysis

either compound could be an issue, it would nevertheless seem prudent to analyse samples for carbofuran and carbosulfan (and any other structurally similar compounds), in addition to any known primary metabolites and degradation products, where feasible. Note that HPLC-MS/MS using multiple reaction monitoring (MRM), discussed in the following section, can differentiate and unequivocally identify these compounds, but such advanced analytical techniques are not available worldwide, particularly in developing countries.

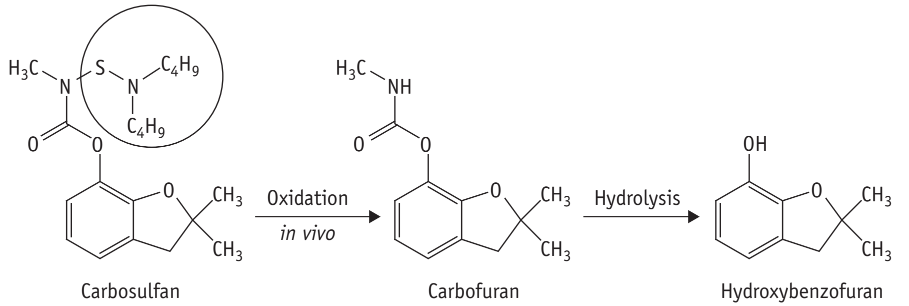

Figure 1.10 Degradation of carbosulfan to carbofuran, via oxidation, then hydrolysis of carbofuran to hydroxybenzofuran

1.5 Analytical methods used to detect carbofuran

The types of samples that are collected for carbofuran residue analysis are further discussed in Chapter 2, and throughout this book. In general terms, an ideal analytical detection method should have a high rate of recovery, a low limit of detection, high selectivity and sensitivity, and good reproducibility (Fodor-Csorba 1998). A number of spectrophotometric and/or chromatographic methods are available for identifying and quantifying the presence of carbofuran in environmental samples. Selecting an appropriate analytical technique depends upon the chemical and physical properties of the compound(s) of interest within a sample, referred to as the analyte(s). In addition, the analytical method is selected on the basis of whether or not the compounds are known targets, or whether a preliminary non-specific screening is required (Maurer 1999). Here, we briefly review the analytical methods that are typically used to assess the presence of carbofuran residues in wildlife samples. Throughout this book, they are referred to as: high performance (or pressure) liquid chromatography (HPLC, Figure 1.11), gas chromatography with mass spectrometry (GC/MS, Figure 1.12), liquid chromatography with mass spectrometry (LC/MS (Figure 1.13, or also LC-MS/MS) and thin layer chromatography (TLC). We also mention a bioassay method, and introduce the concept of cholinesterase inactivation, which is explored further in Chapter 2.

1.5.1 Principles of chromatography

In general, samples to be analysed using chromatographic techniques first undergo a preparation stage, which can include homogenisation, centrifugation, filtration, liquid-liquid extraction, Soxhlet extraction, solid-phase extraction (SPE) and column 'cleanup' before the sample even reaches the instrumental analysis stage (GC/MS or LC/MS for example). All chromatographic techniques are based on the principle that the components (or compounds) within a complex mixture as either a gas or a liquid can be separated and analysed individually using a variety of detectors, by mass or UV/visible spectrometry, for example. Compounds in a mixture are separated as they pass in a mobile phase/state over/through a stationary phase (a liquid or solid). The stationary phase is mounted on a chromatography column-generally, in the simplest terms, a small tube containing the stationary phase. The sample containing the mixture of compounds is washed through the column and the compounds elute from (or leave) the column after a set time (t) which is highly repeatable, and determined by the specific affinity each compound has for the stationary phase. This in turn affects how quickly it will move through the column.

Figure 1.11 HPLC instrument (copyright of Shimadzu Corporation)

Figure 1.12 GC/MS instrument (copyright of Shimadzu Corporation)

Figure 1.13 LC/MS instrument (copyright of Shimadzu Corporation)

Once compounds elute from the column, they can be identified using a variety of detectors which are most commonly based on the mass of the compound (mass spectrometry, or MS), or the wavelength at which the compound absorbs (or re-emits, in the case of fluorescence spectroscopy) light-normally within the UV/visible range, i.e., UV/visible spectrometry. Generally, detection methods which are based on UV/visible spectrometry do not achieve the same sensitivity as those based on mass detection. As such, MS-based instruments, especially tandem instruments such as MS/MS using MRM transitions (as described below), are increasingly becoming the benchmark against which other techniques are measured.

LC-MS/MS (tandem mass spectral techniques) uses chromatography to do the compound separation, then a specific ion is selected, then that ion is broken apart, or, further fragmented). This creates a compound-specific characteristic set of 'jigsaw' pieces. The procedure is known as multiple reaction monitoring (MRM). The products of this procedure can be seen even in a very complicated matrix. If, for example, there were tens of thousands of compounds in a sample, the presence of a particular compound could usually be discerned quite easily. Figuratively, it makes finding a needle in a haystack trivial. This is the type of analysis that is conducted to spot the use of illegal, performance-enhancing drugs in athletes during the Olympic Games.

1.5.1.1 Principles of high performance liquid chromatography

HPLC (with UV/visible detector) uses both a mobile and a stationary phase to separate compounds of interest in a complex solution (or mixture). A sample in a solvent, which also ideally serves as the mobile phase, is forced/washed through a column on which the stationary phase is mounted at relatively high pressure (Harris 2007). Analytes, or compounds, with a higher affinity for the mobile phase, i.e., which do not bind strongly to the stationary phase, migrate more rapidly through the column (Harris 2007). Compounds are then identified on the basis of the characteristic retention time after which they emerge, and importantly, their characteristic profile as determined by the selected HPLC detector.

Aside from 'sample cleanup', an essential step conducted to remove unwanted particles and compounds which would interfere with the detection of carbofuran, samples analysed using this

technique do not generally require any other pre-treatment or modification. Since carbofuran is thermally labile (i.e., sensitive to heat), any residues present in a sample could pyrolysise (i.e., thermally decompose) when injected into instruments that utilise heat during the analytical process, for example a GC. More specifically, the carbamate group (see Figure 1.1) can degrade within the injection port, which is often set from 200 to 350°C. HPLC systems do not use heat at the sample injection point and column heating temperatures are generally low, perhaps up to 40ºC. Hence, HPLC is generally considered the preferred option for isolating carbofuran and its metabolites or to differentiate it from related compounds.

1.5.1.2 Principles of gas chromatography with mass spectrometry

As is the case with HPLC, GC also utilises a mobile (gas) and a stationary (solid/liquid) phase. However GC/MS systems can provide higher selectivity than other GC detectors, and can be used to positively confirm the identity of an analyte in a single 'determination' step. This is because GC/MS systems have very well developed/extensive mass spectral 'libraries' that can be extremely useful for identification and characterisation of unknown compounds. GC does however rely on the compound of interest being volatile at up to 300ºC, which is an important limitation/consideration. As such, certain thermally sensitive analytes may first require derivatisation in order to be detected by GC/MS. Derivatisation is the chemical modification of the analyte(s) to improve detection and/or separation (Harris 2007). A chemical agent is used to react with the compound of interest to form a product that is more thermally stable and often more volatile than the original compound (Maurer 1999; Park, Pyo and Kim 1999). This ensures that the compound/sample can be detected using GC-based techniques; the more volatile the compound, the better it is able to move through the GC column and into the detector.

The analyte (or sample mixture) is injected in solution and rapidly vaporised at the injection port. The latter is the first point of contact between the sample and the column, usually a fine coil of silica capillary tubing, often several metres (e.g., 15 to 30) long, which is held within its own tightly controlled heating compartment. The sample is heated in the injection port and swept through the column held within the oven compartment by a carrier gas (the mobile phase), which is usually helium (Grob and Barry 1995). The column is maintained at either a fixed temperature, or, a series of increasing temperatures can be applied. Depending on the analyte(s) of interest, and the thermal stability of the GC column, the column temperature can be as high as 350ºC.

The eluted compound molecules are bombarded with electrons at a kinetic energy of 70 eV (electron ionisation, EI). Because the electron kinetic energy of 70 eV is much greater than the ionisation energy of the molecules, impact with the high-energy electron stream can remove the electron from the compound of interest with the lowest ionisation energy (Harris 2007). The resulting ion, which then has one unpaired electron, is referred to as the molecular ion, and is denoted as [$M^{+\cdot}$]. This ion generally has so much extra internal energy that it readily breaks into fragments (Harris 2007). Since these fragments, often referred to as m/z ion fragments, are produced with predictable frequency from any one compound, the combination of fragments (and their masses), and the proportion in which they are produced, can be used as a highly compound-specific way to identify the presence of a specific analyte.

A chromatogram (refer to Figure 6.5, Chapter 6) and mass spectrum (see Figures 1.15 and 1.16) are generated as these fragments are detected. These analytical instruments tend to have several analytical modes. In 'scan' mode, the detector will detect, for example, all masses with an m/z value (i.e., the mass to charge ratio) between 100 and 500. The instrument can then create a spectrum, or graph, whereby the x-axis of the mass spectrum corresponds to the m/z value of the ion fragment, whilst the y-axis corresponds to its (relative) abundance (refer to Figures 1.15 and 1.16). A low abundance of parent ion mass [$M^{+\cdot}$] is often observed in GC/MS because the parent ions readily tend to break apart. The most abundant fragment is commonly known as the 'base peak'.

Analytical sensitivity can be increased by specifying certain fragments, i.e., focusing the detector on specific m/z values, or by limiting the scanning interval by reducing it from 100 to 500 down to 150 to 200, for example. When specific m/z values are targeted (i.e., 250, 296, 350), the instrument is set to run in selective ion monitoring or 'SIM' mode. The total ion count (TIC) refers to the sum of the signal generated by all the ions monitored at any one point. The mass spectrum obtained during analysis of the compound of interest is generally verified by comparison against a reference mass spectrum which is often obtained following analysis of the relevant (pure) standard material.

1.5.1.3 Principles of liquid chromatography with mass spectrometry

LC/MS should be viewed as a combination of HPLC and mass spectrometry, in the sense that it employs a mass spectrometer as a detector (Maurer 2000). This technique is often used when the analytes are known targets and need to be quantified accurately (Maurer 2000). While older/more conventional HPLC detection methods may require more complex sample preparations, cleanup and/or more complex column separations, LC/MS generally requires a simpler cleanup and no derivatisation (Hormazábal, Fosse and Reinham 2006).

In LC/MS, the stream of mobile phase containing the analyte(s) of interest emerges into a compartment (an ion-source region before the mass spectrometer) where ionisation occurs by a variety of ionisation mechanisms and at atmospheric pressure. The ion stream produced is then swept or drawn under vacuum through a mass 'selector' or 'filter'. Known as a quadrupole mass filter (which contains four rods that carry voltage and generate an electromagnetic field within the space/void between them, see Figure 1.14), this component facilitates the selection of ions by mass before they arrive at the ion detector.

Compound ionisation occurs in the 'ion-source' region of the mass spectrometer instrument which operates at atmospheric pressure. Two techniques generally prevail: Electrospray Ionisation (ESI) and Atmospheric Pressure Chemical Ionisation (APCI), both of which can be operated in positive and negative ionisation modes (i.e., the detector will be set to monitor positive or negative ions).

Figure 1.14 Quadrupole mass filter (photo courtesy of PerkinElmer, Inc., Watham, Massachusetts (USA))

Dual head systems also exist which combine ESI and APCI, i.e., heat and charge parameters within a single ionisation 'head'. These can be adjusted to make that head more akin to an ESI or APCI system. In ESI, a strong electric charge is imparted to the nebulised eluent as it emerges from the HPLC via an ESI 'probe' (i.e., the interface that essentially connects the HPLC and MS systems). Fine eluent droplets are sprayed into a charged heated chamber and the aerosol droplets undergo rapid size reduction as the solvent (mobile phase) evaporates. Once the droplets have attained sufficient charge density, compound ions are ejected from the surface of the droplet (ion evaporation).

Typical ions generated by ESI include: $[M+H]^+$, $[M+Na]^+$, $[M+NH_4]^+$, $[M+K]^+$ in positive ion mode, $[M-H]^-$ or $[M+Cl]^-$ in negative ion mode, where M is the relative molecular mass of the neutral molecule. In APCI, sample and solvent are again nebulised, converted into an aerosol, and then rapidly heated to a vapour/gas using an APCI probe before entering the ion-source region. The APCI ion-source differs from the ESI ion-source because a corona discharge pin is also incorporated, which typically operates with a discharge current of 2μA. Mobile phase molecules react with the ions generated by the corona discharge and produce stable reagent ions. Analyte molecules introduced within the mobile phase react with these reagent ions at atmospheric pressure and typically become protonated (positive ions: $[M+H]^+$) or deprotonated (negative ions: $[M-H]^-$).

Because of their physico-chemical properties, some compounds have a better response in one ionisation mode than the other. Positive ionisation is usually satisfactory, but there are cases where negative mode should be used because the response in positive mode lacks the required sensitivity.

1.5.1.4 Further analytical options

A number of innovative techniques and adaptations of pre-existing methods are also being developed for the simultaneous separation and detection of multiple pesticide residues including carbofuran, its metabolites and other carbamates. For example, Science and Advice for Scottish Agriculture (SASA), have developed a method (see Chapter 6, Section 6.5) whereby sample preparation and liquid-liquid extraction techniques that separate compounds on the basis of their relative solubilities in a chosen solvent, are combined with gel permeation chromatography (GPC) in order to remove any unwanted material from the test sample (e.g., lipids or proteins) that could interfere with the analysis. The final analytical extract remains a complex mixture, and separation of the components present in the extract is still achieved using either gas or liquid chromatography. Mass spectrometric detection, identification and quantification of compounds of interest with GC/MS or LC/MS can be achieved at ultra-low concentration levels even in the presence of a complex matrix. In the future, the enhanced selectivity/sensitivity afforded by tandem mass spectrometry or time-of-flight (TOF) mass spectrometry will improve the capacity to screen for, and confirm, suspected cases of illegal wildlife poisoning.

1.5.1.5 Carbofuran mass spectrum data

The molecular M^+ of carbofuran has a nominal molecular mass of 221 and, when subjected to electron impact ionisation (EI) in GC/MS, it yields the positive ion (full-scan) mass spectrum shown in Figure 1.15.

The main features of the EI mass spectrum shown are the presence of a small molecular ion peak $[M^{+\cdot}]$ at mass to charge ratio (m/z) 221, and an intense fragment ion at m/z 164 $[C_{10}H_{12}O_2]^{+\cdot}$. This fragment ion is generated by the loss of the $[O=C=NCH_3]$ group from the molecular ion (refer back to Figure 1.1), i.e., a mass difference of 57 m/z units (methyl isocyanate).

In contrast, the main feature of the ESI positive ion full-scan mass spectrum (Figure 1.16) for the LC/MS is the presence of an intense ion at m/z 222 which corresponds to the $[M+H]^+$ molecular ion. The primary fragments at m/z 165 [the phenol $C_{10}H_{13}O_2]^+$ and m/z 123 $[C_7H_7O_2]^+$ are also visible. The small ion at m/z 244 corresponds to the complementary sodium adduct molecular ion (i.e., $[M+Na]^+$).

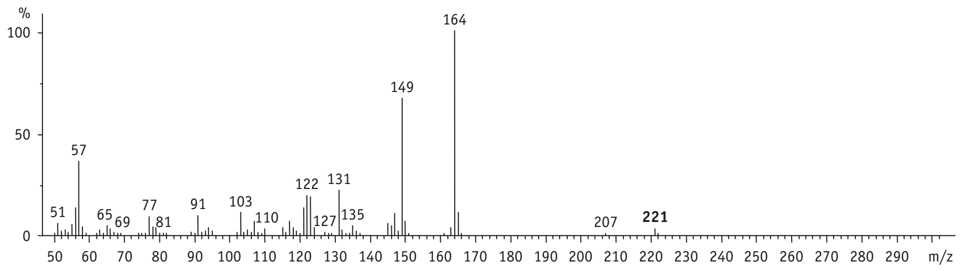

Figure 1.15 GC/MS EI full scan mass spectrum of carbofuran

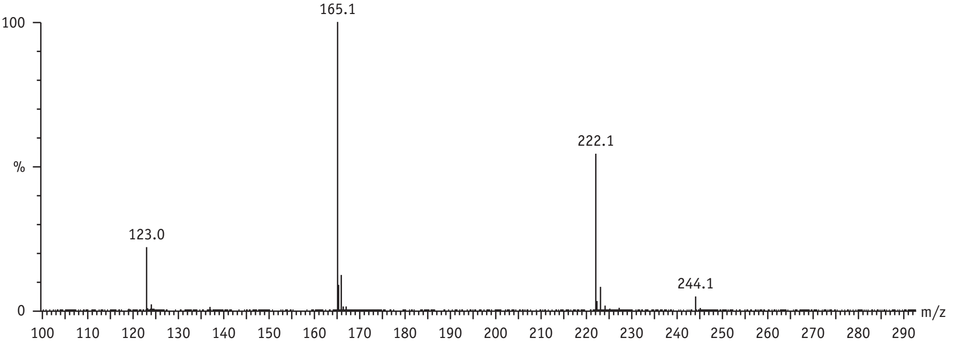

Figure 1.16 LC/MS ESI mass spectrum of carbofuran (in positive ion mode)

The major differences between the mass spectra yielded by each technique (GC/MS with EI or LC/MS with ESI) is due to the fact that ESI is a much 'softer' ionisation technique than EI (and APCI in LC/MS), i.e., ionisation in ESI imparts less internal energy to the molecule and less fragmentation occurs. Hence, there is a much higher relative stability and abundance of the molecular parent ion in ESI. Increased fragmentation can be generated in LC/MS by controlling what is known as the 'fragmentor' voltage which is applied to the ion stream before the quadrupole, but after the ion source. By adjusting this voltage within the method used, greater or lesser parent ion fragmentation can be achieved. This allows a single quadrupole instrument to *begin* to gather more detailed structural information on the compounds being analysed but it falls short of the capability of a highly selective triple-MS instrument which can select and fragment ions more than once (i.e., select specific fragments and then capture/fragment and mass filter those further).

1.5.1.6 Thin layer chromatography (TLC)

Sometimes viewed as an 'old-fashioned' method, especially when compared to some of the analytical techniques described earlier, thin layer chromatography (TLC) can be used to determine the number of components present in a given mixture, assess a substance's purity, and establish, in a preliminary fashion, whether a compound is present in a sample and if further (i.e., more specific) analyses are warranted. TLC is often used for screening because it is rapid, inexpensive and simple to perform once one knows what to look for. Indeed, a TLC plate costs less than 1 USD and, once a TLC chamber is set up, running an additional compound is only a matter of operator time, perhaps 10 minutes or so. By contrast, the cost of analysing a sample via GC/MS or LC/MS, for example, is

based on the use of a very expensive piece of equipment (upwards of 100 000 USD) and on having a highly trained operator who can maintain and run it. In some regards, TLC could be viewed as being more sensitive than other confirmatory means of analyses. Samples of unknowns are often initially analysed by TLC because, even in the absence of the parent compound, the presence of metabolites and breakdown products could be detected, which would not necessarily be the case with GC/MS. However, TLC will only establish the *presence* or *absence* of a carbamate or organophosphorus compound, hence, the sample must then be analysed using more specific confirmatory methods such as GC/MS or LC/MS.

TLC consists of applying a small spot of sample approximately 1.5 cm from the bottom of a plate. The position of the base of the spot is marked with a pencil. The plate will either be a sheet of glass, metal or rigid plastic coated with a thin layer (hence the name) of absorbent material which tends to be silica or alumina-based. When a fluorescent compound is present within the thin layer material, the plate fluoresces everywhere except where there is an organic compound.

Ideally a mixture of known compounds (containing the compound or class of compounds suspected to be in the sample) is added to the same plate for comparison.

Once treated with the unknown sample and the standard control mixture the plate is dried so that all the sample solvent is evaporated. Solvent is then added to a developing chamber in which the plate will be housed. A piece of filter paper is generally placed in the solvent, against the wall of the chamber, which is then sealed for a certain period of time to ensure saturation of the chamber with the solvent. This is to prevent the solvent evaporating from the plate as it moves up the column. Once the plate is placed within the chamber, the solvent is allowed to touch the bottom of the plate, but cannot go above the pencil line (i.e., be in direct contact with the sample spot). The solvent serves as the mobile phase, first dissolving the compound(s) in the sample spot and then being drawn up the plate by capillary action. The material coating the plate serves as the stationary phase.

Separation of the compounds within a sample is achieved due to differences in both their solubility and their affinity or absorption to the plate itself. The retention factor (denoted as the R_f value) measures how quickly the compound progresses up the plate relative to the front, i.e., the solvent or mobile phase. If compounds are coloured, then the components are readily discernible to the naked eye. If not, the plate is viewed in darkness with a UV lamp. The compounds then show up as dark spots on the plate which are circled in pencil. On occasion, the sample will run as a streak or a smear rather than create distinctive spots, making interpretation difficult. If no spots are seen on the plate, then the sample may not be concentrated enough.

TLC is especially useful if a large number of samples must be analysed but few resources are available, i.e., to pinpoint which samples warrant further analysis. In principle, the technique can be used to identify the presence of carbofuran metabolites. Ultimately though, a positive screen result by TLC must still be followed up by confirmatory methods such as GC/MS or HPLC-MS so that the presence of the compound of interest can be specifically and conclusively confirmed.

1.5.1.7 ELISA-based method

Immunoassays such as enzyme linked immunosorbent assays (or ELISAs) use antibodies which react specifically to the analyte in a sample rather than binding or adsorbing to it (Harris 2007). As such, ELISAs could be used to pre-screen samples for presence/absence of carbofuran. First, the analyte contained in the sample or used for calibration is incubated with a polymer-bound antibody, generally on a 96 well microtiter plate (Nelson and Cox 2008), to form a complex which binds to the plate. The fraction of immobilised antibody that binds to the analyte is proportional to the concentration of the analyte in the unknown sample (Harris 2007). The surface of the plate is then incubated with a solution of nonspecific protein, generally casein or bovine serum albumin. This blocks any sites on the plate that do not already have anything bound to them (Nelson and Cox 2008). The complex formed by the antibody and the analyte (of high molecular weight,

e.g., a bacterium or a virus) is then treated with a second antibody which recognises and binds to a different region of the analyte. This type of ELISA is called 'sandwich immunoassay' which is a non-competitive format. This second antibody is covalently attached to an enzyme. After the addition of the second antibody, the plate is washed to clear unbound substances.

In contrast to 'large' analytes, immunoassays to detect small chemicals (e.g., pesticides), rely almost entirely on competitive ELISAs, of which there are two types. In the direct competitive format (i.e., capture assay) the antibody is immobilised on the solid phase (the microtiter plate). Sample analyte and a specially synthesised analyte-enzyme conjugate (the so-called 'label') are added which then compete for the limited antibody on the coated surface. In the indirect competitive format, instead of the antibody, a coating antigen is immobilised consisting of an analyte-protein conjugate. Depending on the assay format, either analyte-enzyme conjugate (direct format) or antibody (indirect format) binding to the surface-immobilised reagent occurs in inverse proportion to the amount of free analyte present in the sample. For further details, the reader is referred to Knopp and Riessner (2004).

The presence of the indicator enzyme enables quantitative analysis because it transforms for example, a colourless reactant into a coloured product (Nelson and Cox 2008). Since one enzyme molecule can catalyse the same reaction many times, numerous molecules of coloured product are created for each analyte molecule (Harris 2007). Hence, the presence of the enzyme amplifies the signal until the reaction is stopped, normally with a dilute acid. The higher the concentration of analyte in the original unknown sample, the more enzyme is bound and the greater the extent of the enzyme-catalysed colour-based reaction. Alternately, the enzyme can convert a non-fluorescent reactant into a fluorescent product. Both colorimetric and fluorescent enzyme-linked immunosorbent assays are sensitive to less than a nanogram of analyte (Harris 2007).

1.5.1.7 Field testing kits

Analytical techniques such as gas and liquid chromatography are very sensitive and reliable, but are simply not practical for field use. These techniques are time consuming and expensive, and must be performed by highly trained operators who can analyse and interpret the results correctly. Field test kits have however been developed to detect the presence of organophosphorus and carbamate compounds in water samples (e.g., in drinking and surface water) and in residues prepared as a dry extract (i.e., evaporated down from a solvent extract). In principle, these kits should be adaptable to environmental samples such as plant matter, soil and wildlife tissues. The test kits are qualitative and colorimetric, meaning that the presence or absence of compounds is determined on the basis of the appearance or lack of a distinct colour. The principle behind the tests is based on the inhibition of cholinesterase activity by organophosphates or carbamates. The reduction of the catalytic activity is dependent on the concentration of the carbamate in contact with the enzyme and can be detected visually or with inexpensive colorimeters.

A popular test kit (the Organophosphate/Carbamate Screen Kit) developed by Abraxis LLC (www.abraxiskits.com) has now been evaluated by the US EPA under the Environmental Testing Verification Program (ETV). The kit utilises acetyl cholinesterase (AChE), which in the absence of an inhibitor (i.e., carbofuran), hydrolyses acetylthiocholine (ATC) which reacts with 5,5'-dithiobis-2-nitrobenzoic acid (DTNB) to generate a yellow colour (read visually or at 405 nm with a spectrometer). Each test kit comes with specific instructions regarding the volumes required and the incubation times needed. The best results are obtained when each sample is prepared in an identical manner. Specific volumes of sample are introduced into assay tubes, an oxidiser is added and incubated for five minutes, this is followed by a neutraliser, then by the AChE, which is incubated for between 15 and 30 minutes. Finally a stop solution is added to terminate the reaction and 'fix' the colour before it is read.

If an organophosphorus or carbamate compound is present in the sample, it will inhibit AChE and therefore the colour formed will be less intense or absent, depending on the concentration present in the sample. As a built-in quality control system, a 'negative control' sample is provided which should develop a dark yellow colour as an indication that the sample does not contain OP or CM. If it does not do so, this means the 'system' is not functioning correctly or the reagents have been contaminated. The detection limit for various pesticides differs, depending on how well they inhibit AChE. The sensitivity of the Abraxis kit to carbofuran is 1.2 parts per billion (ppb), while the sensitivity for other carbamates varies depending on the compound.

As far as we are aware, these test kits have not been validated in tropical environments. Assays performed outside may need to be done away from direct sunlight and at 'reasonable' temperatures, i.e., not at > 40ºC. Reagents must often be stored at a certain temperature, which can certainly be a constraint under some field situations. Likewise, kits often have a shelf life, and as such must be used within a certain timeframe. Finally, depending on the nature of the work, positive results may still require specific confirmation and quantitation using more advanced techniques.

1.6 Conclusions

This chapter described the chemical properties of carbofuran (contrasting these with structurally similar compounds that could interfere with analyses) and the environmental fate of the compound. Its manufacture and formulation was also detailed, and a significant proportion of this chapter was devoted to a comparison of the principles of the instruments and techniques typically used to analyse samples for residues of carbofuran and related compounds. In acknowledgement of the different analytical capacity available in developing and developed nations, we have collated an extensive analytical reference list regarding the detection of carbofuran in a variety of environmental samples. The reference list is available from the editor (through the publisher), upon request.

The next chapter discusses the toxicity of carbofuran to birds and mammals. It provides values that can be incorporated into risk assessments and outlines the signs, symptoms and potential treatment options available for wildlife found to have been poisoned by carbofuran.

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2 Carbofuran: Toxicity, diagnosing poisoning and rehabilitation of poisoned birds

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2.1 Acute toxicity of carbofuran to birds and mammals

Of most relevance to the impacts of carbofuran documented in this book is the acute toxicity of the product. Like other carbamate insecticides carbofuran is a potent and direct cholinesterase inhibitor that is toxic from the moment of exposure without the need for metabolic alteration.

It is sometimes difficult for non-toxicologists to appreciate the comparative toxicity of various substances. We can start by listing LD_{50} values in milligrams of active ingredient per kilogram of bodyweight, a common measure in toxicology circles. This is the median lethal dose, or, the estimated quantity of a substance required to kill half of a set of exposed individuals. However, when thinking about the significance of a given LD_{50} value, a fair degree of mental gymnastics is required, especially when the target organism (e.g., the birds) can vary in weight. Therefore, to provide a more graphic illustration, we will where possible borrow from Rachel Carson's 'Aspirin™ index'. In recognising that the average person may not relate very well to milligram/kilogram values, but that everyone is familiar with a tablet of Aspirin®™, she calculated how many median lethal doses a tablet-sized amount of pesticide would represent. The irony of using this well known Bayer product (Aspirin®™) for this calculation (in view of Bayer's prominent role in the production and marketing of organophosphorous and carbamate insecticides) probably did not escape Ms. Carson. By dividing the number of

Carbofuran and Wildlife Poisoning: Global Perspectives and Forensic Approaches, First Edition.
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median lethal doses in half, we can estimate how many individuals, on average, could be killed from a single tablet-sized amount of the pesticide. We have used this concept in the tables that follow.

Carbofuran is classified by the World Health Organisation (WHO) as extremely hazardous to humans (WHO 1A) based on acute oral rat LD_{50} values as low as 8 mg/kg (Health and Welfare Canada 1987). This same value (a few drops only) is potentially lethal to a mammal of average sensitivity (Table 2.1). In comparison, this value of 8 mg/kg represents the approximate LD_{50} known for the *least* sensitive bird species tested to date (the European starling, *Sturnus vulgaris*). The average toxicity of several carbamate insecticides to the rat, the 'average' mammal and the average bird is given in Table 2.1. Note that it is not unusual for birds to be far more susceptible than mammals to cholinesterase-inhibiting insecticides. This is the case for carbofuran, methiocarb and propoxur – although the trend is reversed for carbaryl (and to a lesser extent aldicarb). Note also that the LD_{50} values given for carbofuran in Table 2.2 are below 1 mg/kg for the two species of waterfowl tested, for half of the songbirds, and for one of the two birds of prey. A single aspirin-sized tablet of technical grade carbofuran contains enough toxicant to kill more than 20 000 red-billed quelea (*Quelea quelea*). In comparison with other pesticides, carbofuran has one of the highest recorded toxicities to birds of any insecticide registered worldwide.

All of these data are for the unformulated technical grade material. The gavage liquid that is used in experiments (unless the material is given neat in a gelatine capsule) can vary from test to test, and this is an important source of variance in the test results. The flowable formulation (Furadan 480F or Furadan 4F in the United States – see Chapter 8) may also be approximately 1.7 times as toxic as the technical grade active ingredient to the same species (E.F. Hill, U.S. Fish and Wildlife Service Bulletin). However, Hill and Camardese (1984) found no significant difference in toxicity between technical grade carbofuran and the 10% sand core granule formulation (Furadan 10G) toward northern bobwhite (a species of quail commonly used for pesticide testing in North America).

Using species sensitivity distributions, Mineau and colleagues (2001) calculated that the LD_{50} value at the 5% species sensitivity tail (a common benchmark amongst pesticide

Table 2.1 Rat LD_{50} values and median mammal and bird values for all species tested. Data from a database compiled by Environment Canada

Compound	WHO listing	Average (geometric) rat LD_{50}	Aspirin® index[a] for the average rat	Median mammal LD_{50} (no. of species tested)	Median avian LD_{50} (no. of species tested)
Carbofuran	1B Highly hazardous	8.7	64	8.9 (6)	1.65 (18)
Aldicarb	1A Extremely hazardous	0.79	709	1.15 (6)	2.82 (10)
Carbaryl	II Moderately hazardous	449	1.2	424 (8)	1870 (7)
Methiocarb	1B	68.7	8.1	40.9 (5)	7.5 (33)
Methomyl	1B	25.4	22	24.5 (7)	23.7 (13)
Propoxur	II	80.3	7.0	146 (6)	11.8 (23)

[a]Number of rats that would be killed by a tablet-sized quantity of carbofuran. Necessary inputs into the calculation: each tablet weighs approximately 392 mg, and a rat weighs 350g (the geometric average of typical male and female weights). Thus, an LD_{50} of 8.7 mg/kg bw means that 8.7 mg would be needed to kill a 1 kg rat (if such existed). Therefore, an estimated 3.05 mg (8.7 × 0.35) is needed to kill a 350 g (average) rat. Since a tablet weighs 392 mg, it contains 128 'potentially' lethal doses (392 ÷ 3.05). And, since only half those doses will actually be lethal (LD_{50}), 1 tablet-sized quantity of carbofuran is sufficient to kill 64 rats.

Table 2.2 Acute oral toxicity of technical grade carbofuran to birds, ordered from the most sensitive to the least sensitive species tested

Species	Sex	Age	LD_{50} (mg/kg)[a]	Aspirin® index for an average adult bird[b]	Source
Fulvous whistling-duck (*Dendrocygna bicolor*)	F	3–6 mo.	0.238	1160	1
Mallard (*Anas platyrhynchos*)	U	33–39 h	0.370		2
	U	6–8 d	0.628		2
	U	27–33 d	0.510		2
	F	3–4 mo.	0.397		1
	M/F	6 mo.	0.415		2
	M[B]	12 mo.	0.480		1
	F[B]	12 mo.	0.510	366	1
	M/F[B]	12 mo. (adult)	0.495		1
Red-winged blackbird (*Agelaius phoeniceus*)	U	adult	0.422	9036	3
Red-billed quelea (*Quelea quelea*)	U	adult	0.485	21382	3
American kestrel (*Falco sparverius*)	M/F	1–4 yr.	0.6	2841	6
House finch (*Carpodacus mexicanus*)	U	adult	0.750	12212	3
House sparrow (*Passer domesticus*)	U	adult	1.33	5320	3
Rock dove (*Columba livia*)	U	adult	1.33	415	3
Brown-headed cowbird (*Molothrus ater*)	U	adult	1.33	3349	3
Common grackle (*Quiscalus quiscula*)	U	adult	2.05	576	3
Japanese quail (*Coturnix coturnix*)	M	14 d	1.9		4
	F	14 d	1.7		4
Eastern screech-owl (*Megascops asio*)	M/F	2–5 yr.	1.9	573	6
Ring-necked pheasant (*Phasianus colchicus*)	F	3 mo.	4.15		1
Northern bobwhite (*Colinus virginianus*)	F	3 mo.	5.04		1
	M/F	16–20 wk.	12		5
	M/F	1–2 yr.	8.0	138	6
European starling (*Sturnus vulgaris*)	U	adult	5.62	425	3

[a]Geometric means calculated where range given

[b]Number of adult birds that would be killed by a tablet-sized quantity (392 mg) of carbofuran. Necessary inputs into the calculation: Each tablet weighs approximately 392 mg; weights for adults of the various bird species were obtained from Dunning (1993).

M = male U = sex unknown

F = female [B] = in breeding condition

1. Hudson et al. (1984)
2. Hudson et al. (1972)
3. Schafer et al. (1983) (range-finding values only)
4. Sherman and Ross in NRCC (1979)
5. Hill and Camardese (1984)
6. Wiemeyer and Sparling (1991)

regulators) for carbofuran was 0.21 mg/kg bw, based on data from 18 species. This value is within the 95% confidence interval measured for the LD_{50} in the fulvous whistling duck, the most sensitive species tested to date. Unlike the situation that prevails with the majority of cholinesterase-inhibiting pesticides (Mineau, Collins, Baril et al. 1996), carbofuran does not show very much scaling of toxicity in relation to bodyweight. Hence, the value of 0.21 mg/kg bw can be used as a 'reasonable worst case estimate' for risk assessment purposes for any avian species regardless of body weight. A 20g songbird at that sensitivity level would have an Aspirin®™ index of approximately 46 800.

The toxicity of carbofuran can also be expressed as the calculated concentration (C) in the feed that would kill half of the test organisms exposed over a standardised feeding (often 5 days) period, referred to as the LC_{50}. The LC_{50} for the technical grade material ranges between 21 and 746 ppm (FMC 1972; FMC 1976; Hill, Heath, Spann, et al. 1975), depending on the species tested and the age of the birds involved. Mallard in these tests proved more sensitive than ring-necked pheasants or northern bobwhites. However, these data are perhaps of limited use. Laboratory based, short-term feeding tests, with the more acutely toxic carbamate and organophosphate insecticides generally appear to underestimate the hazard posed, and the test itself is faulted and has been largely discredited (Mineau, Jobin and Baril 1994).

2.2 Exposure routes for the liquid formulation

Wildlife can be exposed to liquid carbofuran formulations in different ways. Oral exposure through the ingestion of contaminated food is an obvious route conceptually and, indeed, dietary exposure has historically received most of the attention (e.g., Kenaga 1973; Urban and Cook 1986). It is the only route currently considered by regulators in routine assessments (e.g., EFSA 2008, US EPA 2011). However, wildlife can also ingest residues directly, when preening feathers (or grooming fur) and when drinking from contaminated water sources. In addition, dermal exposure can occur via direct contact during spraying, contact with contaminated surfaces after spraying, or through inhalation of fine droplets or vapour. Work on the organophosphates fenitrothion and methyl parathion (Mineau, Sundaram, Sundaram et al. 1990; Driver, Ligotke, Van Voris et al. 1991) indicates that dermal uptake and inhalation can be significant routes of exposure in wild birds. However, the relative importance of each route of exposure is likely to vary tremendously in relation to the chemical involved and the particular exposure scenario (Mineau 1991). Hayes and Laws (1991) indicated that ocular exposure to carbofuran has also caused death in rabbits; however, this route does not appear to have been studied in birds.

Given the number of cases of poisoning noted for waterfowl grazing on sprayed vegetation (see Chapter 8), it may be useful to consider common application rates for liquid formulations transformed into convenient units of poisoning potential. Based on LD_{50} values available for mallard, and application rates registered in Canada for various crops, we have calculated the area of spray deposit which would represent the LD_{50} (assuming negligible drift or volatilisation; Table 2.3). This is a relevant value, whether the dose is ingested with sprayed vegetation, via drinking from a puddle of water, or when a sprayed bird preens. Two scenarios are given: one for a 3-day-old mallard duckling, and the other for an adult mallard. We assume that the relative toxicity of the formulated material to technical material documented by Hill (see Section 2.1) applies to all species and age groups equally.

Most impressive in the calculations outlined in this table is that, at the highest rate registered in Canada, a mallard duckling's LD_{50} would be applied to a surface of less than 1 cm^2. The mallard is also the least sensitive of the two waterfowl species tested by Hudson and colleagues (1972). Whilst these calculations are rather crude/simplistic, they do give a simple indication of just how potentially toxic carbofuran is to wildlife.

Table 2.3 Toxicity of flowable carbofuran (the main liquid formulation) to mallards, expressed as the number of square centimetres of spray deposit needed to achieve an LD_{50} in the test organism

Crops/pests	Labeled application rate in Canada g a.i./ha[a]	No. of cm² per LD_{50}	
		Duckling[b]	Adult[c]
Grasshopper, wheat midge, sunflower beetle in cereals, oilseeds	132	9.1	200
Alfalfa	264	4.5	100
Potatoes, corn, peppers, strawberries	528	2.3	50
Sugar beets	1123	1.1	23
Raspberries, B.C. strawberries	1200	1.0	22
Turnip, rutabaga	2520	0.48	11

[a]Grams of the active ingredient (i.e., the technical pesticide) per hectare of crop
[b]Assuming an LD_{50} of 0.397 mg/kg (Hudson et al. 1972) for the technical material and a weight of 51 g (Martin et al. 1991).
[c]Assuming an LD_{50} of 0.415 mg/kg (Hudson et al. 1972) for the technical material and a weight of 1080 g (Dunning 1993).

2.3 Exposure routes for granular carbofuran formulations

2.3.1 Direct ingestion

Granular insecticides were designed for convenience. They reduce the risk to the person applying the product, and potentially provide a 'timed', or slow/controlled release of the chemical. Since birds do not have teeth, many species regularly consume variable quantities of grit (coarse sand, small pebbles) which then helps them grind their food within their muscular gizzards (part of the digestive tract). This requirement for grit is particularly high in herbivorous birds who consume vegetation (foliage, bulbs, tubers, seeds, etc). It is thought that this is a primary reason why birds actively seek out and consume pesticide granules (mistaking them for grit particles), although they probably also mistake them for seed. Grit is retained within the gizzard, even when a bird is fasting and once food has actually passed down the alimentary canal (British Ornithologists' Union 1985). The main manufacturer of carbofuran reports that at least 45 avian species, from 17 different families, have been killed during their supervised field trials involving silica granular formulations (FMC 1986, and see Chapter 8).

Consumption of just one to five granules of Furadan 10G can be fatal to small birds (Balcomb, Stevens and Bowen 1984a, and see Chapter 3 and Chapter 7). An average 10G granule (based on a mean weight of 0.320 mg; Hill and Camardese 1984) contains 0.032 mg of active carbofuran, which represents the approximate LD_{50} for a small songbird. A corncob-based granule which was also marketed in Canada as Furadan CR-10 was larger (2.25 mg; Maze, Atkins, Mineau et al. 1991) and contained about 0.22 mg of active carbofuran. A single CR-10 granule was therefore capable of killing even a large-bodied bird, or some of the least sensitive songbirds.

Again, it is useful to consider the application rate of the granular formulations in terms of 'relevant units of poisoning potential'. For granular formulations, where granules are actively sought and eaten by birds (very much the case with carbofuran), knowing the total number of granules applied to an area may be useful when considering the potential for effects in wildlife, considering just one

Table 2.4 Number of granules applied per metre of row for the 10G formulation of carbofuran. Numbers represent registered use patterns in Canada prior to the product being cancelled in 1995

Crop	Rate of application of the granular formulation (g/100m of row)	Usual row spacing (cm)	Equivalent rate of application (kg a.i./ha)	Number of granules applied per metre of row
Maize (field, sweet, silage)	110	75	1.47	3438
Onion (dry from seed)	70	40	1.75	2188
Potato	300	90	3.33	9375
Rutabaga, turnip	175	70	2.50	5469
Sugar beet	50	60	0.83	1563

granule may well kill a bird; Table 2.4. As we can see, almost 10 000 granules may be applied in just one metre of crop row.

In maize, the most efficient implement available for delivering a banded application (a subsurface T-band application) typically leaves 6.5 to 8.1% of granules at the soil surface (Mineau and Clark 2008). Over 50% of granules are left on the surface at turn points (at the row ends) and automatic shut off systems can only bring this number down by one half (Mineau and Clark 2008). Surface banding of granules, followed by more standard covering techniques using rakes, tines, chains, etc., can leave up to 40% on the surface. Given the number of granules applied, their attractiveness to birds, and the fact that a single granule may be lethal, it is not surprising that granular carbofuran has proven so efficient at killing birds (see Chapter 8).

In a laboratory study, Kenaga (1974) reported that northern bobwhite given *ad libitum* (i.e., unrestricted) access to clean (pesticide free) clay granules, consumed up to 4.9 g/week or 0.70 g/day. Given that each granule weighed about 0.064 mg (Hill and Camardese 1984), this would correspond to approximately 11 000 granules ingested per day. By weight, this would represent approximately 2 200 Furadan 10G granules, or just over 300 larger Furadan CR-10 granules. However, this extremely high consumption rate for clay granules is not typical of other grit types, which may be less prone to rapid breakdown (i.e., hard/quartz gravel).

The ingestion of granules and dietary grit by birds in the field has been investigated in a systematic fashion (Best and Gionfriddo 1991a, 1991b; Best 1992; Best and Fischer 1992). It is now apparent that silica-based granules (such as most of the carbofuran products sold worldwide) are extremely attractive to birds. Silicates, quartz, and feldspar are the most commonly sought after grit material in wild passerines, although this will obviously depend on local availability. The fact that carbofuran 10G or 15G tends to be much more spherical than ‘typical’ grit material does not seem to deter birds. Corncob granules such as carbofuran CR-10 also tend to resist breakdown in the gizzard, and therefore may be retained in this part of the digestive tract (as is grit). Given the choice, birds may select harder grit, and therefore reduce their overall consumption. Both silica and corncob carbofuran granule formulations tend to resist breakdown in the field, and are therefore available to birds for longer periods of time (Fischer and Best 1995).

In one study undertaken in Utah cornfields (see Chapter 8), 831 horned larks (*Eremophila alpestris*) and 81 individuals from other species were found dead following the ingestion of either the 10G or 15G formulation (FMC 1983). The number of granules ingested was recorded for all carcasses with intact gastrointestinal tracts. The results by species are given in Table 2.5. This sample is known

Table 2.5 Frequency distribution of carbofuran granules in the gastrointestinal tracts of 555 birds poisoned in Utah cornfields

	Number of granules in the gastrointestinal tract, and % of those dead containing that number						
Species	0	1	2	3 to 5	6 to 10	>10	Sample size
Horned lark (*Eremophila alpestris*)	18.0	20.3	15.4	23.8	12.8	9.70	479
Brown-headed cowbird (*Molothrus ater*)	64.5	16.1	6.5	6.5	6.4	0	31
Yellow-headed blackbird (*Xanthocephalus xanthocephalus*)	50.0	10.0	15.0	15.0	10.0	0	20
All birds	22.2	18.9	14.4	22.7	12.3	9.50	555

to be biased toward indicating a smaller number of granules, since it does not include granules that passed through the birds' digestive tract (although, given the speed of onset of toxicity, this may not be a serious bias).

The maximum number of granules found in one horned lark was 53. The median number in horned larks was two, and 22.5% individuals of this species had ingested more than five granules. From a diagnostic point of view, it is interesting that *no* granules were found in almost one quarter of all the casualties.

A study by the Bayer Corporation (Fischer and Best 1995) investigated the ingestion of blank (pesticide free) silica granules in birds. These authors found no relationship between the number of granules on the soil surface and the mean gizzard count in a group of blackbird species. Such a relationship did, however, exist for a group of sparrow species. They found that a reasonable 'worst case estimate' for silica granule consumption by small songbirds was 25 granules per day.

2.3.2 Contaminated soil invertebrates

It has been recognised for many years that carbofuran is extremely toxic to earthworms, and that dead worms can contain enough residue to kill flies attracted to the carcass (e.g., Kring 1969). Also, carbofuran granules can adhere to earthworms. Even when granules are washed off the worms, whole body residues can range between 0.3 and 670 ppm (in 11 of 12 worms analysed following a 1.1 kg a.i./ha in-furrow application to corn; Balcomb, Bowen, Wright et al. 1984b). The average residue in this study was 84.7 ppm. At the maximum level reported, ingestion of a single large mature worm (*Lumbricus terrestris*: 15 cm, 5 g; Cathey 1982) would result in a dose of 43.5 mg/kg bw for an average-sized American robin (*Turdus migratorius*: 77 g; Dunning 1993). At the average residue level reported, a single worm would represent a dose of 5.50 mg/kg bw. Given that this value is higher than most LD_{50} values reported for songbirds, we can conclude that a worm with an average body burden is likely to be lethal to an adult robin. The risk would obviously be greater if granules physically adhered to the worm. The risk to nestlings would also be higher because of their small body size and high food consumption rate relative to their size. A similar hazard is predicted for foraging American woodcock (*Scolopax minor*; Eisler 1985). In the United Kingdom, a buzzard (*Buteo buteo*) found dead with earthworms in its beak has also tested positive for carbofuran (Fletcher, Hunter, Greig-Smith et al. 1989). No details were given regarding any pesticide application involved; it is therefore unclear whether the granular or flowable formulation was implicated.

Dietricht and colleagues (1995) also reported on a large mortality of buzzards, as well as black and red kites (*Milvus milvus* and *Milvus migrans*, respectively). These birds were killed via the ingestion of earthworms in a beet field that had been treated with granular carbofuran applied in-furrow. Earthworm residues peaked at 3.2 ppm in one seeded field studied by Dietricht, Schmid, Zweifel et al. (1995). Stinson, Hayes, Bush et al. (1994) further report the poisoning of American kestrels following an application of the 15G formulation in-furrow. Stomach contents of two birds affected contained only insect parts.

The acute LD_{50} of technical grade carbofuran in the mouse is approximately 2.0 mg/kg bw (NRCC 1979). It is therefore likely that small mammals such as moles and shrews, which regularly consume earthworms, are very much at risk from the use of granular carbofuran. Observed behavioural changes in exposed worms, such as muscle spasms and coiling, are likely to attract predators (reviewed in NRCC 1979). There is no readily available information regarding carbofuran in (or on) other soil invertebrates. Any such contamination of invertebrate fauna would certainly add to the already high risk of exposure.

2.3.3 Contaminated soil/sediments

Carbofuran granules have caused many instances of waterfowl mortality, in flooded or partly flooded fields (see Chapter 8). When fields flood (or puddles form), even if this occurs a long time after application, waterfowl (primarily) are often attracted to those fields. They then sift waterlogged sediments in search of food, and drink the contaminated water. The label for Furadan 10G specifies that the granules should not be applied to soil subject to flooding. Problems have primarily arisen in acidic soils, where granules have a much longer half-life (Getzin 1973). Root crops are often grown on soils where there is high water retention. Clearly, it is often difficult for growers to foresee puddle formation or flooding which may take place some time after the application of the pesticide. Wilson and colleagues (2002) found that granulated carbofuran followed a logistic decay model in both silt loam and muck soils (in the lower Fraser Valley of British Columbia). Very high initial retention of the active ingredient occurred, and half-lives of 129 and 97 days for the two soil types were noted, respectively. Further discussion of half-life and fate in tropical soils can be found in Chapter 3.

2.4 The time course of carbofuran intoxication

Early studies which related cholinesterase levels to acute exposure to carbamates are those of Bunyan and Jennings (1976) and Westlake, Bunyan, Martin et al. (1981), although these authors did not test carbofuran specifically. One finding which emerged was that for a number of carbamates, birds that died within two hours of exposure did not necessarily demonstrate any inhibition of brain acetylcholinesterase (AChE). Brain AChE inhibition only became obvious at higher (e.g., 2 x LD_{50}) doses. Westlake and colleagues suggested that this may be because carbamates have a higher affinity for neuromuscular junctions (relative to organophosphates). Death from carbamate intoxication is typically very rapid, e.g., it occurs after just 9 to 18 minutes, for three granular carbamate insecticides (Balcomb, Stevens and Bowen 1984a). Hence, an animal presumably dies of respiratory arrest long before significant quantities of the insecticide pass into the brain. On the other hand, plasma cholinesterase (ChE) was much more indicative of exposure at > 2h post dosing, whether the animal died or survived. At 24h post dosing, the plasma activity of survivors returned to normal, and in some cases was higher than in controls.

2.5 Physiological effects and signs of intoxication

The following discussion is adapted from Mineau and Tucker (2002). Overstimulation of the somatic nervous system (which controls voluntary muscle movement by a pooling of acetylcholine) typically results in tremors, muscle twitches and piloerection (erection of the contour feathers), as well as paresis (slight or incomplete paralysis) resulting in ataxia (lack of coordination/stability). More rarely, an animal may convulse. Cholinergic tracts are also important to both the parasympathetic and sympathetic autonomic nervous systems, but especially to the former. They conduct impulses from the neural ganglia to a multitude of organs such as the heart, the endocrine glands, and the digestive system. Because the autonomic nervous system is subject to constant adjustment through feedback mechanisms, intoxication with a cholinesterase inhibitor is rarely straightforward. For example, individuals may show either constriction or dilation of the pupils, or a speeding up or slowing down of the heartbeat, and so on. Also, because the somatic and autonomous systems react to different levels of cholinergic stimulation, some doses of a cholinesterase inhibitor may produce apparently opposite signs (e.g., contraction of the striated muscles involved in locomotion, and simultaneous relaxation of the smooth musculature leading to a flaccid gut and food impaction). Poisoned raptors, for example, are often found with very full crops.

The rate at which an individual is exposed to a cholinesterase-inhibiting pesticide is often as important as the dose itself. Typically, gradual exposure allows the individual to compensate for, and thus tolerate, a higher dose than if the exposure was due to a single large dose. This is especially true for carbofuran and other carbamates because rapid spontaneous recovery from intoxication can occur via the hydrolysis of the enzyme-pesticide moiety. Porter (1993) cautions that many 'classic signs' of parasympathetic stimulation (as reported in standard toxicology texts) may not be seen in carbamate poisoned raptors, and certainly not with any consistency. Often, clinical signs may be non-specific and may only involve depression or ataxia. Shimmel and Snell (1999) also note that it is often difficult to arrive at a conclusive diagnosis without chemical or biochemical laboratory backup. Nevertheless, the following list (modified from Grue, Hart and Mineau 1991) summarises the signs noted by Hudson and colleagues (1984) following dosing using various bird species (in the laboratory) with a variety of cholinesterase-inhibiting agents:

- ataraxia (induced tranquility), lethargy
- ataxia (incoordination of muscular action)
- blindness
- convulsions, particularly just prior to death
- defecation, diarrhoea
- dyspnea (difficult breathing)
- epistaxis (bleeding from the nares [nostrils])
- exophthalmia (protruding eyes)
- hyperexcitability
- lacrimation (secretion/discharge of tears)
- miosis (contraction of pupils)
- myasthenia (muscular weakness)
- mydriasis (dilation of pupils)

- opisthotonos (heads and limbs arched back)
- paresis (slight paralysis)
- piloerection (erection of contour feathers)
- polydipsia (excessive thirst)
- ptosis (drooping of eyelids)
- slurred vocalisations
- tachypnea (rapid breathing)
- tenesmus (spasmodic contraction of anal sphincter)
- tremors
- vomiting

Typically (but not always) poisoned birds die of anoxia (lack of oxygen) because of respiratory failure. This is as a result of one or a combination of factors, i.e., excessive secretion in the respiratory tract, bronchoconstriction, failure of the muscles required for respiration and/or failure of the respiration centre (see Gallo and Lawryk 1991 for a review). With carbamates, individuals who survive the initial exposure are less likely to suffer long-term consequences than those exposed to organophosphorous pesticides. However, any continued presence of the insecticide in the gastrointestinal tract can lead to a lengthy rehabilitation period.

The following are observations made on a large number of birds of prey brought to rehabilitation centres in British Columbia and subsequently found to have been poisoned by carbofuran.

- The arrival of dead or moribund birds appeared to follow periods of rain.
- Birds were lethargic, uncoordinated and often unable to stand.
- Some had depressed core body temperature, a symptom reported for several cholinesterase inhibitors.
- Birds had constricted pupils and a 'fixed vacant' stare.
- Some had a brownish oily exudate from the mouth, and a noticeable 'chemical odour' on the breath.
- Birds were typically in good flesh, and had distended crops.
- After emptying crop contents (manually, or at times, by surgical excision), recovery commonly occurred very rapidly (often described as 'miraculous').

These birds had been consuming waterfowl that had been killed by granular carbofuran up to seven months after application to the fields (Elliott, Langelier, Mineau et al. 1996). A similar lag time between application and mortality has been reported after US rice applications (Littrell 1988).

2.6 Physical field evidence and necropsy findings in poisonings due to AChE inhibiting compounds, with special emphasis on carbofuran

Dead birds often provide the primary evidence in poisoning events caused by AChE inhibiting compounds. Sometimes, small birds such as sparrows, cardinals and robins are presented dead or dying, while larger birds such as starlings, crows, hawks, and eagles may be exhibiting clinical signs. Suspicion of poisoning is heightened if birds from multiple species are found dead in a limited geographic area. Birds may also be discovered in varying degrees of postmortem condition

if the initial mortality is not detected quickly, and then new arrivals have had continued access to the chemical. In carbofuran poisoning incidents, carcasses are commonly found adjacent or in close proximity to bait material (see Figure 2.1).The area immediately surrounding a carcass may well appear disturbed, as a bird may have seizures or struggle before succumbing to the pesticide. The feet or talons may be clenched around vegetation; another indication of seizure or agonal contraction. This is not a common finding in non-poisoning cases. The crop and oesophagus are often visibly distended with ingesta, and birds can die so quickly that the ingested food may be present in the mouth (for example, see Figure 2.2). Note also the rigid angle of the tail feathers of the birds shown in Figures 2.1 and 2.2 (and see Figure 7.5 in Chapter 7).

Birds are generally in good body condition, with adequate pectoral muscling. Male geese and ducks poisoned by carbofuran may be found with a prolapsed penis. The only other condition historically associated with a prolapsed penis is duck plague (duck virus enteritis), a herpes virus infection that occurs in ducks, geese and swans. If poisoning is suspected, the authorities should be notified so that carcasses and field samples can be collected in a manner that would support a successful legal investigation and to minimise further environmental (e.g., further poisonings, environmental contamination) and human health risks.

A diagnostic evaluation of a carcass should rule out infectious agents. Although there is no pathology specifically associated with birds poisoned with carbofuran, wet lungs, congested tissues, and occasionally, haemorrhage in the intestine can be seen. When the oesophagus, crop, and gizzard/stomach are opened, they are almost always full. As discussed above, the toxicant/compound can be directly consumed as granules, and these may be visible. Likewise, the liquid formulation can be

Figure 2.1 In carbofuran poisoning incidents, carcasses such as these marsh harriers are commonly found adjacent or in close proximity to baited material (i.e., the hare)

Figure 2.2 Birds can die so quickly that they are discovered with poisoned ingesta in their mouths

used in malicious poisoning, and may be applied to seed, processed meat, or, a multitude of other bait material (depending on the intended target). Poisoning may also occur via the ingestion of dead and/or dying insects, or from ingestion by scavengers of dead and/or dying birds or other vertebrates. In cases of suspected poisoning, brain samples should be collected to assess AChE activity. If not analysed immediately, brains (or the whole head) should be frozen as quickly as possible. The contents of the oesophagus, crop and stomach/gizzard (upper gastrointestinal content) should be saved (in two separate bags). One can be used as the primary sample for residue analysis, the other for identification of the contents. It may be advisable to keep a sub-sample as well, in case there are legal proceedings. These should also be frozen to prevent residue degradation.

An accurate history is often very helpful when making a tentative diagnosis of carbofuran poisoning, and when directing any residue work. Knowledge regarding any sprays or granules that have been used in the proximity of the incident is critical – and such questions should always be asked of anyone reporting the incident. A detailed history is likely to include species present, species affected, environmental conditions (i.e., recent rainfall), high temperatures (which might have led to sample reactivation or chemical breakdown). A detailed identification of the upper gastrointestinal content is also critical when trying to understand the kill; photographs can be helpful. Wobeser (1996) provides generic guidance on forensic examination techniques, and emphasises the need for clear reporting, and a carefully maintained chain of custody (so that a case can be presented in a court of law if needed). Finally, investigators must wear the appropriate protective clothing to minimise health risks and prevent accidental exposure since the area of the kill could be heavily contaminated. Investigators must also consider that the need to quickly recover samples may conflict with normal allowable re-entry intervals into the area, which could be heavily contaminated from a spill or from malicious baiting.

2.7 Chemical and biochemical diagnosis of a carbofuran kill

Diagnostic confirmation of a carbofuran kill tends to be achieved via the analysis of brain AChE, and using chemical residue analysis. Grue and colleagues (1991) reviewed in detail the extent of cholinesterase inhibition that is associated with acute poisoning for all cholinesterase-inhibiting pesticides. Their conclusions were similar to those presented previously on the subject (e.g., by Hill and Fleming 1982), i.e., that mortality is likely when brain depression levels of 50% or more occur. Since diagnostic centres often deal with severely autolysed (decayed/degraded) samples, some adopt a more stringent rule for diagnosing fatal intoxication. For instance, pathologists at the USGS National Wildlife Health Centre use a 75% inhibition cut-off as an indication of poisoning if upper gastrointestinal tract contents are not available for analysis. They will attempt to have samples analysed chemically if brain activity levels are down by two standard deviations or more from the normal mean activity level (corresponding to approximately 20% inhibition) or when case history suggests that it is warranted. It should be noted that, the higher the diagnostic criterion of inhibition, the more likely bias will be introduced, namely the likelihood that cases of abuse (where concentrated bait was involved) will be diagnosed, but not incidental intoxication from normal product use. Inhibition of > 75%, with recovery on overnight incubation, triggers a diagnosis of 'likely carbamate intoxication', even when there is no residue analysis undertaken.

The potential for rapid, spontaneous recovery of cholinesterase activity following carbamate intoxication means that it can be particularly difficult to use cholinesterase depression as a diagnostic tool (in the case of carbofuran poisoning; Hill 1989). Reduced cholinesterase activity (especially if the sample spontaneously reactivates in the laboratory) is diagnostic. However, the absence of inhibition does not necessarily mean that there was no intoxication. For this reason, a review of all raptor carbofuran intoxications noted between 1985 and 1995 for Canada, the US and Great Britain (as tabulated in Mineau, Fletcher, Glazer et al. 1999), failed to show a clear/consistent relationship between brain cholinesterase depression and carbofuran residue concentration in the gastrointestinal tract. This could also reflect a poor relationship between typical gastrointestinal tract residue analysis and the amount of toxicant actually absorbed into the blood stream. There are many reasons why reported levels in the gastrointestinal tract may not reflect the toxicological response, not least, the quality/representativeness of the sample analysed and the quality of the residue analysis itself, to name but two.

In certain cases, the suitability of both the cholinesterase measurements and the residue determinations can be compared. Hill and Fleming (1982) describe how 4/5 wigeons (*Anas americana*) were picked up around 1.5 days after dying from carbofuran intoxication. In this case, their brain AChE values had returned to normal even though carbofuran residues were still detectable in the gastrointestinal tract (the residue levels were not given). Wigeon picked up the day before, in a moribund condition, exhibited brain AChE inhibition ranging from 54 to 77%.

Flickinger, Mitchell, White et al. (1986) analysed 16 carcasses of dickcissels (*Spiza Americana*) and savannah sparrows (*Passerculus sandwichensis*). These had died when ingesting seed rice illegally treated with carbofuran, and 12/16 carcasses analysed had > 20% brain AChE inhibition. Residue levels in the gastrointestinal tracts of the same birds ranged from not detected (ND) to 10 ppm carbofuran.

Flickinger, King, Stout et al. (1980) diagnosed carbofuran poisoning in four shorebirds after recording the presence of granules in their stomachs. Balcomb et al. (1983 and 1984b) used residues in liver and the digestive tract combined to diagnose carbofuran poisoning in songbirds collected from corn fields where granules had been used. The carcasses were said to be 'fresh' when collected. Five of six carcasses collected in one of the study years were positive for carbofuran, with levels between 1.6 and 17 ppm. Based on granule weight data (Hill and Camardese 1984), the carbofuran extracted from each bird was between 0.2 and 1 granule (equivalent). In another year, 'selected birds'

were reported. These had between 1 and 5.4 granule equivalents in them. One red-shouldered hawk (*Buteo lineatus*), collected moribund and sacrificed, had 1.5 granule equivalents in its stomach contents and the same amount in its digestive tract tissue (from the ingestion of contaminated prey). Ten common grackles nesting near the treated fields were not exhibiting any toxicosis, but were nonetheless collected and analysed. Nine had measurable carbofuran residue levels. The mean for all 10 birds was 0.87 ppm. All carcass collections were made 72 hours post carbofuran field treatment, but exposure could have occurred at any point up to the time of collection given that granules can persist for some time on the soil surface.

As noted, the spontaneous postmortem reactivation of cholinesterase enzymes is known to take place following carbofuran exposure (as is the case for most carbamates). For example, Ludke, Hill and Dieter (1975) fed three week old Japanese quails a diet contaminated with 600 ppm carbofuran for 4 hours then allowed the carcasses to age before carrying out analysis. Reactivation, though not complete, but was certainly well underway after 24 hours at 35°C. Reactivation was slight after two days at room temperature. Reactivation of brain samples was noted but was not complete in a study by Bunyan and Jennings (1976), who were able to diagnose brain ChE inhibition despite 5 days aging at room temperature. They warned that the very large doses used on the birds may have been sufficient to mask/prevent spontaneous reactivation. The definitive study, however, was that of Hill (1989) who showed a clear temperature-dependant reactivation of samples from birds killed by carbofuran.

Hunt, Hooper and Littrell (1995) reported on the reactivation of ChE in brain samples from several heron species killed by aquatic runoff containing carbofuran in a vineyard. Reactivation was slower than expected, suggesting that there may be interspecies differences in the speed of reactivation, or that any unbound insecticide in the samples could interfere with reactivation. Elliott, Langelier, Mineau et al. (1996) and Mineau and Tucker (2002) also described one case where spontaneous recovery was only possible after residual insecticide had been removed from the sample with a gel permeation column. Hunt and Hooper (1993) have provided guidance on various aspects of sample reactivation, including variations in relation to temperature, dilution, solvents used, and regarding the solid phase extraction of unbound pesticides from samples. Other examples/guidance regarding reactivation assays can be found in Smith, Thomas and Hulse (1995).

Analytical data showing carbofuran is present in a carcass is *usually* a finding of significance. However, we should caution that increased analytical sensitivity now means that modern equipment can detect very low/trace levels, and that such levels may be of questionable physiological significance (particularly in large birds like goose or grouse species that may inhabit farmland). Carbofuran is readily absorbed from the avian digestive system (Hicks 1970), is then readily metabolised, and can easily degrade within samples. In a study by FMC (the primary manufacturer of carbofuran), investigators were unable to detect the insecticide in many of the bird carcasses they had spiked (i.e., deliberately treated the carcasses with carbofuran) in the field (see Chapter 8, Section 8.4.1.3.) although this may have been related to a fault within the techniques used, either low levels of spiking or inadequate analytical methods. Mineau and Tucker (2002) have reviewed the carbofuran levels found in the gastrointestinal tracts of birds determined to have been poisoned by carbofuran. They found that values ranged from < 0.1 ppm to > 1 000 ppm, i.e., by four orders of magnitude. Values at the upper end of this range (e.g., > 100 ppm) were typically associated with baiting and cases of criminal poisoning. However, there was significant overlap between cases of abusive poisoning and cases of poisoning caused by registered use, with the majority of data falling between 1 and 100 ppm, for both types of incident. Authors of Chapter 5 (see Section 5.5.3) describe how inexperienced poisoners use an enormous amount of poison while 'professional poisoners' use very small amounts which makes it more difficult to detect.

A promising forensic technique may involve the extraction of bound residues from bird feet. Vyas and colleagues (2005) placed eastern screech-owls (*Megascops asio*) on a piece of deer carcass contaminated with flowable carbofuran for 40 minutes, to mimic a malicious baiting situation. They euthanised the owls, and placed their feet outdoors at temperatures ranging from 13 to 30°C

over a 28 day period during which 164 mm of rain fell. No apparent postmortem loss of residue was recorded. Otieno and colleagues (2010) have also recently extracted residues from the beaks and talons of poisoned vultures. Based on their findings, they suggest that the two main breakdown products (3-hydroxycarbofuran and 3-ketocarbofuran) should be analysed in addition to the parent material (carbofuran proper). These metabolites were present in certain cases, even when the parent compound had completely disappeared.

Whether residues are detected within gastrointestinal contents, in feet, or in the beak, converting these figures into lethal-dose equivalents (for the purposes of proving causation) is often not simple or perhaps even useful. Unfortunately, pathology reports often state that the gastrointestinal residue level was below the LD_{50} value, and that therefore the pesticide probably did not kill the animal. For many reasons, this is scientifically unsound. Gastrointestinal tract contents are pre-absorptive (i.e., they do not indicate the amount that has already entered the animals' circulatory system and target organs) and, different parts of the gastrointestinal tract can present very different residue load values (as described above).

Much of the above discussion assumes that a bird will die quickly after carbofuran ingestion. However, delayed mortality is also possible. Birds that are sub lethally exposed to cholinesterase inhibitors, for example, are known to be more susceptible to predation (Galindo, Kendall, Driver et al. 1985; Buerger, Kendall, Mueller et al. 1991; Hunt, Bird, Mineau et al. 1992). There is also anecdotal evidence which suggests that sub lethal exposure may make animals more vulnerable to collision with objects, either moving (e.g., vehicles) or stationary (e.g., power lines, fences, buildings). Upon arriving at a rehabilitation centre, a raptor for example, may often be diagnosed as a victim of 'collision'. The suggestion that pesticides may well be involved in at least some such cases is two-fold: (1) there is anecdotal evidence available (from rehabilitation centres) when cholinesterase measurements are taken as a matter of routine (e.g., Porter 1993); and (2) a wealth of human based evidence shows that various visual/motor effects can be recorded in humans (see Gallo and Lawryk 1991 for a review) after they are occupationally exposed to organophosphorus and carbamate insecticides. Blurred vision is a common complaint, and unequal miosis can also lead to a phenomenon called the 'Pulfrich Stereo Effect' where depth perception/the ability to compute trajectory is affected. Assuming that these physiological effects can extend to birds, one may imagine that birds could thus suffer more collisions in flight.

2.8 Rehabilitation of poisoned wildlife

Normally, the treatment of choice is to remove all food contents from the upper gastrointestinal tract. If the bird being treated has an engorged crop, this must be emptied. The crop contents can be gently manipulated toward the pharynx and then removed manually, or the bird may be anaesthetised for this procedure. Alternatively, the bird may be anaesthetised but if manual manipulation is not possible, an ingluviotomy (an incision made to the crop of the bird) can be performed and the crop contents carefully removed. This is then followed by intravenous or intramuscular (i.e., IV or IM) atropine administration. The recommended dose is usually within the 0.5 to 5.0 mg/kg range. However, Shlosberg and colleagues (1997) argued for a much higher dose (of 50 mg/kg) after working with young chickens and the carbamate insecticide methomyl. They attributed this requirement for a higher dose to the presence of hydrolytic enzymes in chicken blood (atropine esterase), and, recommended that an appropriate atropine esterase regimen should be developed for various wild bird species. Atropine will only alleviate the clinical signs of toxicity, and will not affect cholinesterase levels. If the only obvious sign is depression, no improvement may be noted. The antispasmodic drug diphenhydramine (at 15 mg/kg) is often used if a bird is exhibiting tremors or twitching.

There is a long-standing belief that oximes (such as 2-PAM – pralidoxime chloride) should not be used in cases of carbamate poisoning. Oximes are very effective at breaking the

insecticide-cholinesterase bond in the case of organophosphorous compounds. However, (as reviewed by Shlosberg and colleagues (1997)) standard veterinary textbooks vary tremendously in relation to their recommendations regarding carbamates. Some merely indicate that oximes will not be of any benefit when carbamates are involved, whereas others explicitly warn against their use. Shlosberg, Bellaiche, Hanji et al. (1997) found no enhanced toxicity occurred when using 2-PAM on methomyl-poisoned broiler chicks, and hence suggested that oximes may be safe with many carbamates. 2-PAM is certainly not safe with carbaryl, the carbamate on which the most work has been done in this regard. Since it is commonly difficult to identify the offending cholinesterase-inhibiting agent (when a poisoned bird is brought into a rehabilitation centre), an oxime may still be used (despite the above contraindications).

Supportive therapy is important in any case, and this can include fluids and gastrointestinal protectants that contain activated charcoal (such as Toxiban® or Liquichar®). In some cases, where these products were administered to bald eagles before the crop was emptied, the birds regurgitated. Although aspiration of the activated charcoal product and/or the crop content is a potential risk to a neurologically compromised bird, the administration of activated charcoal prior to physically emptying the crop may prevent the need for anaesthesia and/or surgery. Long term nutritional support is also necessary, and if affected birds do not eat on their own, hyper-alimentation will be needed.

If a bird has been sprayed by a carbamate, or had contact with contaminated surfaces, its feet and feathers should be washed thoroughly with warm 5 to 10% dishwashing detergent solution (Dawn® is the commercial brand usually recommended; it is also used for oiled bird recovery). Otherwise, the bird will re-ingest the toxicant while preening and clinical signs will return.

Generally, even if a bird's clinical signs are totally alleviated, the bird will still not be neurologically normal. Affected birds must therefore demonstrate the ability to find and/or kill prey before they are released. This usually requires up to two weeks in captivity.

2.9 Conclusion

This chapter provided a review of acute toxicity values of carbofuran in birds and mammals, listed exposure routes to both liquid and granular formulations of the product and discussed the timeline of intoxication, in birds at least, although the situation is similar in mammals. We also described the effects of intoxication, outlined typically associated signs, summarised clinical and field evidence that one should be on the lookout for, discussed biochemical diagnosis of carbofuran poisoning and considered rehabilitation approaches. We hope that this information will be useful to colleagues who encounter scenarios of intoxication such as those detailed in the rest of this book.

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3 A chronicling of long-standing carbofuran use and its menace to wildlife in Kenya

3.1 Introduction

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Africa has long been alluring to foreign visitors, particularly those intent on seeing the 'big five' (i.e., lions, elephant, rhinoceros, buffalo and leopard) on safari, or on bringing back a memento from a hunting expedition. Most visitors expect to find an entirely 'wild' landscape, as often depicted in nature films, whereas in fact there is now an extreme contrast between the protected and unprotected areas. In some protected areas (e.g., the Mara) the settlements literally reach the doorsteps of the reserves. The core issue is the growth of the human population and subsequent movement everywhere, to the point where many wildlife corridors and buffer areas are completely dominated by people. The expansion and emigration of people and agriculture into previously vacant areas near parklands and protected areas has considerably intensified the human-wildlife conflict, which in turn has resulted in a number of retaliatory measures.

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Since firearms are difficult for most Kenyans to legally obtain, poisons are widely used to control predators/pests and to (illegally) harvest bushmeat (Odino, Ogada and Musila 2008). Inexpensive, readily available and highly toxic poisons are most effective, and, for all these reasons, Furadan has been especially popular as a poison in Kenya. Initially imported into the country in the 1960s for use in rice paddies, Furadan first appeared on the radar of Kenya's conservation movement in the mid-1990s, when it was misused in rice schemes to kill ducks and other waterbirds, which were then harvested for human consumption (Odino and Ogada 2008a, and see Section 3.3).

After this illegal use of Furadan was specifically flagged as a potential issue, talks were undertaken with FMC Corporation (the minutes of these and ensuing discussions can still be found in the Ornithology Section of the National Museums of Kenya). As a result of these initial meetings, FMC officials stated that they had attempted to make one of their products (i.e., Furadan 5G) unpalatable to granivorous birds, an attempt which apparently proved to be unsuccessful. There was then a general loss of momentum regarding the wildlife poisoning issue by all sides concerned. When, nearly 20 years later, what is sometimes referred to as 'the carbofuran menace' resurfaced (in June 2007 to be exact), the same researchers and wildlife conservationists, many of whose work is detailed within this chapter, regrouped and invested considerable effort in generating awareness at the community level, nationally and internationally.

In 2007, following an increasing spate of lion and vulture poisonings in northern Kenya (i.e., Isiolo District), the Bird Committee of Nature Kenya allocated funding for an intern from the National Museums of Kenya's (NMK) Ornithology Department (Martin Odino, author of Section 3.3) to survey farmers and agrovets regarding the misuse of Furadan and other agro-chemicals to intentionally poison wildlife. The survey and research conducted in parallel revealed that not only was Furadan being used to kill animals for food, it was also widely viewed as a means to kill 'nuisance' animals including crocodiles (in the Tana River), squirrels and hawks on farms, and stray dogs (i.e., Odino and Ogada 2008a). Previous reports of birds, hyenas, lions and hippos (among others) that had (allegedly) been poisoned using Furadan, and that had been brought to the attention of the Kenya Wildlife Service (KWS) and other Kenyan wildlife conservation authorities since the early 2000s, were also consolidated/highlighted (Kahumbu 2009). Unfortunately, for reasons discussed in Section 3.8, few of these findings have been corroborated by forensic analysis or investigation.

In response, a meeting was convened with representatives from conservation groups, researchers and governmental agencies, including NMK, BirdLife International, World Wildlife Fund (WWF)), Nature Kenya, KWS, WildlifeDirect and representatives from the Pest Control Products Board (PCPB) on 25 April 2008 and a taskforce was set up. The first 'Stop Wildlife Poisoning' taskforce meeting was held later in April 2008, and those in attendance were appraised of the magnitude of the problem, not just for lions/mammalian scavengers and vultures, but also for fish and aquatic birds, which had received (and still receive) far less attention.

A year or so later, on 29 March 2009, a segment titled 'Poisoned' (which examined the allegation that Furadan was being used to poison lions and was indirectly killing vultures and hyenas in Kenya) was aired on the popular American television program '60 Minutes' (http://www.cbsnews.com/video/watch/?id=5189491n&tag=related;photovideo). Shortly after that, FMC announced that it would retrieve unused Furadan supplies in Kenya through a buy-back programme, which commenced in May 2009. On 13 February 2010, FMC announced on their website that they had ' . . . repurchased Furadan 5G from distributors and retailers in Tanzania, Uganda and Kenya,' and that 'The buy-back programme remains open for any product that might still be in

commercial channels . . . FMC has no plans to reintroduce the product in these countries in the future' (http://www.furadanfacts.com/InTheNews.aspx?itemId=1002).

Since then, Furadan has become more difficult to access in Kenya, as many agrovet proprietors will inform customers (incorrectly) that Furadan has been 'banned'. As a result of the buy-back programme, purchasing Furadan has now gone 'under the table', such that it is sold by the spoonful to those who are 'in the know'. However, there is anecdotal evidence that carbofuran, whether Furadan or otherwise, can still readily be sourced from nearby Tanzania (R. Bonnham, personal communication, 2011) and Uganda.* Indeed, a recent survey indicated that carbofuran was readily available in about 80% of the sampled agrovet stores in Uganda (Okot Omoya and Plumtre 2011). In areas around Queen Elizabeth National Park, retailers openly stated that their customers used carbofuran not only as pesticide but also as poison against 'problem animals' such as lions, monkeys and baboons (E. Okot Omoya, personal communication, 2011). An incident of lion poisoning on the Kenyan/Tanzanian border in the Amboseli region, allegedly implicating carbofuran, occurred as recently as January 2011 (see Section 3.4).

Consequently, the current (as of 2011) and pressing ecological/economic concerns stem from the possibility of regional extinctions of lions and vultures, discussed in more detail in Sections 3.4 and 3.5, respectively. The lion, a top predator and highly charismatic, emblematic species, is a key element of Kenya's tourism sector, and vultures are an absolutely integral component of any healthy ecosystem. There is now a genuine concern that the lion population in Kenya may be extinguished within the next decade, if not before (Frank 2010). In combination with the concerted efforts of stakeholders, the resulting adverse publicity and international perceptions that followed the '60 Minutes' television segment have culminated in mounting pressure to ban Furadan in Kenya. The 'sticking point' remains a dearth of robust and extensive forensic/toxicological evidence specifically implicating carbofuran in comparison to the number of incidents of wildlife mortality (see footnote * above). This situation is incredibly frustrating to those on the ground who have good intelligence implicating the product. Fortunately, an increasing amount of residue data is being collected, and concerted efforts are being directed towards enhancing the necessary sampling and analytical capability (see Section 3.7). For example, the first forensic analysis of carbofuran exposure to vultures in Kenya through improper use (in poisoned baits) has recently been established in Isiolo and Laikipia Districts, using high precision analytical instruments (Otieno 2009; Otieno et al. 2010b). This case is further detailed in Section 3.6.

In order to understand how things in Kenya (and other parts of Africa) reached this point, it is first necessary to have a sense of the agricultural and rural way of life in the country. This chapter therefore begins with a discussion of how carbofuran (in this case Furadan) was introduced into Kenya and previous use patterns (Section 3.2). Trends in the use and handling of pesticides (including carbofuran) in agricultural communities and a brief discussion of the presence, persistence and degradation of the compound in the Kenyan environment are also included.

Case studies detailing a variety of incidences of wildlife mortality have been provided by key researchers on the ground, and reflect the full range of threats posed to wildlife and biodiversity in Kenya. A map of Africa (see Figure 3.1) has been provided to facilitate the reader's journey through the case studies. The chapter concludes with a review of the remarkable array of governmental and regulatory mechanisms that have been enacted to address unsafe and illegal uses of pesticides, thereby illustrating in large part why the process to get a firm handle on the incidents of wildlife poisonings and illegal uses of pesticides has been anything but straightforward.

Figure 3.1 Map of Africa, prepared by John C. Nelson and Wayne E. Thogmartin, United States Geological Survey, Upper Midwest Environmental Sciences Center)

3.2 Background on pesticide use and environmental monitoring in Kenya

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3.2.1 Furadan use in rice farming: how carbofuran first gained entry into Kenya

On a global scale, carbofuran is most often used in rice cultivation (Meister and Sine 1999), and this industry is very important in Kenya. According to the existing records, carbofuran was first imported into the country in the 1960s (as Furadan), mainly to control rice pests, although other uses such as control of maize stock-borers in maize, sorghum and millet have also been reported (Lalah 1994; Otieno 2009). Carbofuran has a lower LD_{50} than other insecticides such as acephate, diazinon and ethylan and hence is more effective for control of susceptible and moderately resistant rice cultivars (Barrion and Litsinger 1994). Table 3.1 summarises the quantity of carbofuran imported into Kenya between 1986 and 1992, because we were unable to find any records regarding the quantity of carbofuran imported after that. We note that the available data show that elevated quantities of technical carbofuran have been imported at a rate comparable to malathion, an organophosphorus insecticide used worldwide in horticultural farming and grain storage (Lalah and Wandiga 1996c; PCPB 2006). When recently surveyed, farmers in Isiolo and Laikipia District stated that they considered Furadan to be the best line of defence against insect pests (Otieno 2009, and see Section 3.6).

According to the records, carbofuran was primarily imported (as Furadan 5G) to control soil-dwelling and foliar-feeding insects. The most recent PCPB reports (i.e., from 2006) indicate that Furadan 5G, 3G and 10G granules were marketed to control soil insects and nematodes and early foliar feeding insects (see Table 3.2). These granular formulations were packed in 200 and 500 gram plastic bottles and sold freely over the counter in most agrovet shops in Kenya. A liquid formulation (Furadan 350ST) was also marketed as a seed dressing, mainly for barley seeds. However, we researched and provided this written contribution in 2009/2010, and there have since been a number of significant developments in the availability of Furadan and related products on the Kenyan market (see Section 3.4). As a result, the information provided within this section should be regarded as confirmed up until 2009, since the current status and availability of Furadan in Kenya is largely speculative at this point.

The major irrigation schemes where Furadan was used in commercial rice farming, with the support of the National Irrigation Board of Kenya (NIB), were in Yala, Ahero, Mwea and Tana River. In Ahero, Mwea and Tana River, the farms were either owned by NIB (which was involved in farming and marketing rice) or by the farmers themselves. In Yala, all farms were owned by individual farmers rather than by NIB. We note that these schemes became inactive in the late 1990s but were revived in 2009 following a call by the government for intensification of irrigation agriculture, in response to severe food shortages that followed long periods of drought. Unfortunately, recent information regarding Furadan/carbofuran use in these schemes does not appear to be available.

Table 3.1 Annual importation of insecticides/acaricides, carbofuran and malathion into Kenya between 1986 and 2004

Year	Total (tonnes)	Insecticides and acaricides (tonnes)	Carbofuran (technical) (tonnes)	Carbofuran (technical) (litres)	Malathion (technical) (tonnes)
2004	7672	3278	ND	ND	ND
2003	7205	2987	ND	ND	ND
2002	6826	2747	ND	ND	ND
2001	5651	2320	ND	ND	ND
2000	4432	1762	ND	ND	ND
1999	6179	2186	ND	ND	ND
1998	7606	1814	ND	ND	ND
1997	5828	2078	ND	ND	ND
1996	6946	1876	ND	ND	ND
1995	5109	1413	ND	ND	ND
1994	4032	1050	ND	ND	ND
1993	3553	839	ND	ND	ND
1992	6590	1670	23	15 000	10
1991	4051	1072	10	21 000	13
1990	4893	1572	12	16 000	19
1989	7711	1571	7	10 000	16
1988	8257	1089	14	NI	9
1987	3929	1206	30	2 000	15
1986	2650	1076	8	NI	20

Source: Pest Control Products Board of Kenya (PCPB, 2006)
Total: includes insecticides/acaricides, herbicides, fungicides and others (not classified)
NI: not imported
ND: no data available

In the 1980s, fields were regularly sprayed with insecticides including carbofuran, fenitrothion and DDT to control agricultural pests and mosquitoes. All the rice schemes in Ahero (in Nyando District) were aerially sprayed (using Furadan 5G, which came in 200 g packages, at a cost of 140 KSh/ca. 2 USD each) in response to an outbreak of some of the common rice pests including army worm (*Spodoptera frugiperda*), bacterial wilt aphid and black rot (Ouma 1983). However, no specific details of exact quantities used during each aerial spray nor application rates were given. Dimethoate, diazinon, lambda-cyhalothrin (Karate) and the acaricide amitraz (Triatix) were also used at this time.

Ministry of Agriculture reports (Anonymous 1980) from the 1980s describe the Yala Integrated Development Plan, which supported rice farmers by providing funding to offset the cost of pesticides and irrigation equipment, and the services of district government advisers. These reports contain information on carbofuran use in small-scale projects (up to 50 hectares), medium-scale projects (50 to 1 000 hectares) and large-scale projects (above 1 000 hectares). Rice and other crops including vegetables, maize, beans and sugarcane were grown in farms gravity-fed from the River Yala. The soils in this area are well drained, deep, friable clays in the catchment with gentle slopes and imperfectly drained firm impermeable clays along the streams (see Section 3.2 for a discussion on the role of soil content in pesticide retention).

Under the Integrated Development Plan, the average price of Furadan for farmers on a typical sized plot (i.e., 1.6 hectares) was 15, 80 and 305 KSh (a range of approximately 25 cents to 4 USD)

Table 3.2 Summary of some reported uses of Furadan in rice and other crops farming from 1969

Area	Pesticide use	Cost (KSh)	Rate of application	Primary purpose
Yala (Yala Integrated Development Plan)	Furadan 5G	15 to 310	28 kg used	Rice farming (vegetables, beans, sugarcane)[a]
Ahero (1980)	Furadan 5G[b]	140	200 g used	Rice farming (outbreak of armyworm, bacterial wilt aphid and black rot also reported)
Ahero (1982)	Furadan 5G	not given	not given	Rice farming (trials with new rice varieties)
Ahero (2000)	Furadan 5G[c]	not given	500g used	Rice farming
Tana River[d] (1992–1993)	Furadan 5G	not given	not given	Control of maize stalk-borers in maize, sorghum and millet
Laikipia and Isiolo[e] (2008)	Furadan 5G	not given	not given	Maize and wheat farming

[a]Other plants and crops grown within the scheme
[b]Other pesticides used: dimethoate (100ml), diazinon (20 ml), lambda-cyhalothrin/Karate (100ml), amitraz/Triatix (100ml), chlorfenvinphos/Steladone (100ml)
[c]Other pesticides used: diazinon, lambda-cyhalothrin/Karate, mancozeb/Dithane M45
[d]Lalah (1994)
[e]Otieno (2009)

in 1969, 1975 and 1980, respectively. Although there were no records of the market price of Furadan, these costs were most likely offset by government subsidies, which helped farmers with the costs related to farm maintenance and agrochemicals. The final costs of such ‘assistance’ were then deducted from the sales of the farmers’ produce. Records indicate that a total of approximately 28 kg of Furadan was applied annually in the Yala scheme.

In 1982, trials with two varieties of rice were conducted over one season at the Ahero Irrigation Research Station (Anonymous 1982). Diseases and pests were monitored during the growing season and instances of Furadan use were recorded (although the quantities used were not). The paddies were linked by canal and irrigation water from River Nyando and Lake Victoria was discharged to the canal via water inlet and outlet pumps. A 1991 report details training activities on the safe use of agrochemicals in Narok District. Wheat and maize were the main food crops, and there was intensive use of pesticides including oxydemeton-methyl (Mestasytox 20L, 120 units used per year), carbosulfan (Marshal 5L, 20 units per year), lambda-cyhalothrin (Karate 20L, 125 units per year), malathion 200 ml (40 units per year), diazinon 20 ml (100 units per year). Use of Furadan was not reported, which may be because its use there was still confined to rice crops (Anonymous 1991). The use of Furadan to control maize stalk borer pest after an outbreak in maize, sorghum, and millet crops was reported in Tana River District in 1992 and 1993 (Lalah 1994). A Nyando District annual report listed use of Furadan 5G, diazinon, lambda-cyhalothrin and mancozeb (Dithane M45) in 2000 in the Ahero scheme (Anonymous 2006).

Furadan has recently been used in maize and wheat farming in the Tana River District (Otieno 2009). Table 3.3 lists the formulations that were available in Kenya as of 2009. Whereas carbofuran has been implicated in numerous instances of avian and wildlife mortality in agricultural areas within North America (see Chapter 8 for examples), the repercussions that may have ensued from legal and directed applications made in the rice farms and settlements in Kenya remain essentially unknown/undocumented. Recent reports have indicated that carbofuran is being misused, to poison

Table 3.3 Formulations of Furadan available in Kenya (as of 2009)

Furadan Formulation	Purpose and mode of application	Crops applied to	Recommended rate of application (kg ai/ha)
3G	Insecticide/nematicide used in seed dressing, applied with seed treatment equipment, mechanical applicators	Barley, wheat	0.74 – 6.7
5G	Insecticide/nematicide used in seed dressing, applied manually	Bananas, beans, rice, coffee, maize, pineapples, pyrethrum, vegetables	0.5 – 4.0
10G	Insecticide/nematicide used to control soil insects and early foliar feeding insects, granular applicator	Bananas, coffee, maize, pineapples, pyrethrum nurseries	0.26 – 2.0
350ST	Insecticide/nematicide used in seed dressing	Barley	not known

birds, in West Kano, Busia District (Odino and Ogada 2008a, b). Such use of carbofuran to deliberately poison birds in settlement schemes is described in greater detail, in Section 3.3.

3.2.2 Presence, persistence and degradation of carbofuran in Kenyan soils

Following on from the previous section, which detailed applications of Furadan in agricultural areas, primarily rice settlement schemes, this section briefly discusses the environmental fate of carbofuran. The adsorption, leaching and dissipation of carbofuran have been extensively examined in Kenyan soils. Studies indicate that the compound is fairly soluble in water, moderately mobile in soil, and that the speed of its dissipation depends largely on the soil type and prevailing climatic conditions (Lalah and Wandiga 1996a; Lalah and Wandiga 1996b; Lalah, Kaigwara, Getenga et al. 2001). Some of the physicochemical characteristics of carbofuran, and its behaviour in Kenyan environments (in contrast to other pesticides) are summarised in Table 3.4.

Clay and organic matter content are two of the major factors which determine the adsorption of carbofuran in soils. When the organic carbon content of soil exceeds 6% (as is the case in the very rich soils typically found in forested regions in temperate countries), the pesticide molecule binds solely onto the surface of the organic carbon present. However, when the carbon content falls below the 6% threshold, the pesticide binds to both the soil mineral (clay) and organic matter (Calderbank 1989). The organic matter content in typical Kenyan agricultural soils ranges from 0.54 to 1.68%, which suggests that, in agricultural areas, adsorption of carbofuran and its interaction with soil is controlled by both the clay and organic matter content.

Tropical conditions (i.e., elevated temperatures and high moisture rates) promote the rapid diffusion and volatilisation of pesticides (Lalah, Kaigwara, Getenga et al. 2001). Under field conditions, the half-lives of dissipation of carbofuran are shorter, on average, in Kenyan soils (ranging from 66 to 115 days) than in temperate soils (ranging from 18 to 378 days; Lalah and Wandiga 1996a; Lalah, Kaigwara, Getenga et al. 2001). A more detailed discussion regarding the composition of

Table 3.4 Physicochemical properties of carbofuran and its fate in Kenyan soils compared with other commonly used insecticides

Physico-chemical property	Carbofuran	DDT	Malathion	Lindane
Molar mass (g/mol)	221.3	354.5	330.4	219
Water solubility (mg/L)	700	1.2×10^{-3}	145	7.0
Vapour pressure (mbar)	2.6×10^{-5}	1.7×10^{-7}	1.6×10^{-4}	1.7×10^{-4}
Log K_{ow}	1.23−1.42	4.98	2.36	5.23
Melting point (°C)	147	108.5	285	112
DT_{50} (days) in Kenyan soils	66−96.3	64−110	36.7−770	5−8
DT_{50} (days) (Furadan) non-flooded soil	115.5	NA	NA	NA
Soil bound residue formation % (range)	9.0−52.7	0.16−5.9	2.2−11.4	0.19−6.0
Soil bound residue formation (Furadan) %	9.6−48.1	NA	NA	NA
Freundlich constant K_f (range) Kenyan soil	1.5−1.7	ND	1.7−1.8	ND
Freundlich constant 1/n (range) Kenyan soil	1.0	ND	0.70−0.81	ND
K_{OC}	22	2.45×10^5	291	1.1×10^3
% leachate (48 hr standard leaching test)	29−33	ND	2.2−37.8	ND
Acute oral LD_{50} birds mg/kg body weight	1.65	$840-2.24\times10^3$	$100-1.49 \times 10^3$	$75-2 \times 10^3$
24 hr LC_{50} fish *Oreochromis niger* mg/L	0.225	*0.002−0.042	*0.06−10.7	**0.02

NA: not applicable
ND: not determined
DT_{50}: half-life
'LC_{50}'denotes 'lethal concentration to cause 50 percent mortality in study group, *96 hr LC_{50} in various species
**NOEC, 'no observed effect concentration' in fish
References: Lalah and Wandiga (1996b); Lalah, Kaigwara, Getenga et al. (2001); Wandiga, Lalah and Kaigwara (2002)

Kenyan soils and factors that influence carbofuran interaction and disappearance from tropical soils can be found elsewhere (e.g., Lalah, Kaigwara, Getenga et al. 2001). Other factors, such as soil pH, also play a role in adsorption/desorption (Haque 1975; Calderbank 1989).

Significant residues of carbofuran and its metabolites (3-ketocarbofuran and 3-hydroxycarbofuran, see Figure 1.9, Chapter 1) were recently detected in unflooded agricultural soils in Laikipia and Isiolo, where Furadan was applied to control pests in maize (Otieno 2009, and see Section 3.6). Laboratory and field studies carried out at the Ahero Irrigation Scheme, where carbofuran has been extensively applied in rice paddies since the 1980s, showed that the compound readily degrades in both unflooded and flooded soils to yield several breakdown products including: 3-ketocarbofuran, 3-hydroxycarbofuran, carbofuran phenol, 3-hydroxycarbofuran phenol and 3-ketocarbofuran phenol. Most of the residues were detected within the top 10 cm layer in flooded soils (Lalah and Wandiga 1996a) where they would also be available to fish, birds and other aquatic organisms. A more detailed discussion of the leaching and retention rates of carbofuran (and metabolites) in Ahero and Chiromo soils can be found in Lalah and Wandiga (1996a).

Flooding suppresses the amount of oxygen present in soil and, as a result, the hydrolysis (i.e., decomposition by reaction with water) of carbofuran under flooded conditions tends to be chemical, as opposed to microbial. In flooded non-sterile, anaerobic (i.e., absent of oxygen) soil conditions, carbofuran is more rapidly hydrolysed but its hydrolysis products (carbofuran phenol and 3-hydroxy carbofuran) resist further degradation (Venkateswarlu, Siddarame-Gowda and Sethunathan 1977). The persistence of carbofuran in submerged soils has also been confirmed in other tropical countries such as the Philippines and China (Caro, Freeman, Glotfelty et al. 1973; Aquino and Pathak 1976; Venkateswarlu, Siddarame-Gowda and Sethunathan 1977). A number of enzymes, bacteria and fungi also facilitate the degradation of carbofuran in soil and aquatic environments (e.g., the microorganism *Actinomyces*, which is responsible for converting carbofuran to carbon dioxide (McRae 1989). A number of other microorganisms involved in the process, including *Pseudomonas, Flavobacterium*, *Achromobacter*, *Arthrobacter*, *Sporocytophaga* and *Corynebacterium* have also been identified in soils and are discussed elsewhere (e.g., McRae 1989; Lalah, Kaigwara, Getenga et al. 2001).

Although carbofuran and its metabolites have been detected in soils in Kenya and the degradation process is well understood, the mechanism/process of metabolism in non-target organisms such as fish, birds and other wildlife species has not yet been formally investigated. The findings discussed in this section indicate that carbofuran (in the form of its metabolites) is fairly persistent in irrigation systems, which may pose an ongoing exposure threat to aquatic organisms. Given that some of the metabolites formed from chemical and microbial degradation of carbofuran are highly toxic (3-hydroxycarbofuran and 3-ketocarbofuran are the two of greatest concern, as outlined in Chapter 1), a directed investigation of soil and water-dwelling organisms is essential in order to better understand the toxicity of these metabolites within the environment.

3.2.3 General purchase and application of pesticides

Sections 3.2.1 and 3.2.2 discussed the use of pesticides (primarily carbofuran/Furadan) in rice cultivation and the environmental fate of the compound in Kenyan soils and agricultural areas. This section provides an overview of the distribution and use of pesticides in Kenya. The pesticide industry in this country is composed of a) companies that manufacture the active ingredients used in pesticide formulations, b) companies that incorporate the active ingredients into the formulations and c) representatives of manufacturers and/or importers of pesticides and related products not otherwise represented in Kenya (Wandiga, Lalah and Kaigwara 2002). The Pyrethrum Board of Kenya extracts pyrethrins (i.e., botanical compounds with insecticidal properties) from pyrethrum (a herb in the *Asteraceae* family). The Kenya Farmers Association (KFA) is involved in the distribution of pesticides. Most representatives of pesticide manufacture and distribution are overseas-based and include companies such as Rhone Poulenc, Twiga Chemicals, Murphy Chemicals, Shell Chemical Industries and British East Africa (BEA) Company.

A great many insecticides/acaricides, herbicides, fungicides, and others not classified (e.g., avicides, rodenticides and miticides) are imported into Kenya every year. Approximately 20% of pesticides are imported in technical form (i.e., as active ingredients) then formulated locally, while the rest are imported as ready-to-use, formulated products. Most farmers in Kenya buy pesticides from retail stockists, distributors, or through their cooperative societies and unions. Financial incentives are sometimes available to farmers, especially to members of the cooperative societies. Furadan and related carbamate pesticides are marketed through the company Juanco Ltd. According to the PCPB, Furadan is imported for 'restrictive use' only (i.e., by 'informed' operators/users). PCPB deems that pesticides classified as 'restricted' are extremely toxic and should only be handled by trained, experienced and well-equipped operators who are licensed by

the Board (Otieno 2009). However, our experience 'on-the-ground' indicates a distinct lack of monitoring by the Board and other authorities to ensure that experienced personnel are handling/applying carbofuran and to deter misuse.

Unfortunately, most Kenyan farmers lack the basic knowledge of the inherent risks of handling and applying pesticides, which often leads to indiscriminate use, incidental exposure, excessive application and an inability to identify banned or restricted products (Wandiga, Lalah and Kaigwara 2002). This situation is not helped by the fact that many of the banned products nonetheless find their way back onto store shelves and become available once more to farmers. Faced with many products on the market, several factors tend to influence a farmer's choice, including the prices of the products available, the formulation (whether liquid, granular or powder), the physicochemical properties of the formulation (e.g., smell) and how it is delivered (often by public transportation, which is more convenient for people in rural areas; Wandiga, Lalah and Kaigwara 2002). They may be swayed/advised by agricultural extension officers or by successful and more 'knowledgeable' farmers, or they can simply be compelled to purchase a pesticide because of the container it is sold in (e.g., if it can be reused for other purposes). Most farmers store their pesticides with other household goods or farm produce. Kimani and Mwanthi (1995) reported that some community members rinse empty pesticide containers at community water sites, which could lead to severe poisoning and contamination of drinking water sources (although no such incidents have been documented).

Tractor-mounted sprayers and knapsack sprayers are amongst the most commonly used applicators. Aircraft-mounted sprayers are most often used to control outbreaks of army worms, tse tse flies or locusts (Wandiga, Lalah and Kaigwara 2002). Cattle dips are widely used for treatment with pesticides, but livestock may also be sprayed using '*jua kali*' (i.e., unorthodox) methods such as fly whisks, specially bound leaves and brooms (Nyaga 1988). Those who spray, mix pesticide solutions or clean up after pesticides have rarely worn protective clothing, mainly because of its cost, but also because it is uncomfortable in the temperature and humidity. Because the effects of pesticides are delayed in people, symptoms tend not to be attributed to pesticide exposure and hence, go undiagnosed and largely untreated (Nyaga 1988).

3.2.4 General trends in use of pesticides in agricultural communities

This section briefly considers other pesticides and pesticide use patterns in Kenya. The annual Provincial and District Agriculture reports, kept in the archives of the two departments at their headquarters (the Ministry of Agriculture library located at Agriculture House in Nairobi), contain a wealth of historical information regarding the various agricultural and veterinary pesticides and their use at the farm level. These records chronicle the use of pesticides in Kenya over the last few decades, both for agricultural and veterinary purposes, and generally indicate an increase in the amounts of pesticides imported annually (see Table 3.1).

Lindane was first introduced in 1949, toxaphene in 1950, DDT in 1956 and dieldrin in 1961. Other compounds introduced in the 1950s include dinitrocresol (DNC, used as an herbicide and fungicide) and organophosphates such as: tetraethyl pyrophosphate (TEPP), schradan, dioxathion and coumaphos (Keating 1983). In the last decade, compounds such as aldrin, endrin, endosulfan, trichlorphon, malathion, parathion, dimethoate, fenitrothion, diazinon, chlorfenvinphos, chlorpyrifos, dichlorvos, polythion, carbaryl, carbosulfan, cypermethrin, deltamethrin, lambda-cyhalothrin, diuron, 2,4-D, atrazine, alachlor, glyphosate and hexazinone have also made their way into the Kenyan market (Lalah 1994; Wandiga, Lalah and Kaigwara 2002).

The use of many of these pesticides, particularly by large-scale farmers, enabled control of a vast number of tropical agricultural pests and serious insect and tick-borne diseases in livestock

(Kaine 1976). In this regard, the Department of the Crop Protection Division of the Ministry of Agriculture and the Veterinary Department have played a prominent role in generating public awareness about the selection, purchase and application of pesticides. Both departments have also been instrumental in promoting the use of specific pesticides in agriculture, at the farm level, through extension services that provide training, demonstrations and consultancy to farmers.

The livestock industry has been threatened by diseases such as East Coast fever (theileriosis), an acute cattle disease caused by ticks, and anaplasmosis, an infectious disease in ruminants caused by blood-sucking insects. The organophosphorus compound chlorfenvinphos has been extensively used in vector control in livestock (Keating 1983; Kituyi, Wandiga and Jumba 1997; Wandiga, Lalah and Kaigwara 2002). DDT was mainly used to control the malaria vector (i.e., the *Anopheles* mosquito), particularly during outbreak of disease (Mosha and Subra 1982; Wandiga, Lalah and Kaigwara 2002).

In the public health sector, World Health Organisation (WHO) programmes have helped control vector-borne diseases such as malaria, African sleeping sickness, bilharziasis (transmitted by parasitic flukes of the genus *Schistosoma* Sambon) and fascioliasis (transmitted by liver flukes of the genus *Fasciola L*). Pesticides have been used to control vectors including mosquitoes, tse tse flies and water snails (*Biomphalaria pfeifferi* Krauss (Gastropoda: Planorbidae)), respectively, in the Mwea Tabere settlement scheme, Kano Plain and Lambwe Valley, for example (Wandiga, Lalah and Kaigwara 2002). In such instances spraying was prescribed by the government-supported programmes to make these areas habitable for people.

The records in the Ministry of Agriculture library, from the 1980s and 1990s, were quite detailed, often indicating the types and quantities of pesticides used (refer back to Section 3.2.1). However, when we paid a visit to the library in 2009, we were unable to find most of the District and Provincial annual reports for the period from 2000 to 2009. And, when reports were available, the identity and amount of pesticides used were either completely absent or lacked the meticulous detail of the reports from prior decades. To us, this served as an indication that current national agricultural records of agricultural inputs, including the amounts and rates of application of agrochemicals, need to be more rigorously maintained and brought back to the previous standards. These differences are indeed evident in Table 3.1.

In the late 1990s, approximately 33% of Kenyan farmers, primarily large-scale farm operators, used pesticides. Most small farms operated on a subsistence level, with minimal use of pesticides (Kanja 1988; Wandiga, Lalah and Kaigwara 2002). Current usage patterns have changed since then, especially in the horticultural industry which has expanded very rapidly. For example, flower exports have increased tremendously as an industry, and about 50% of all UK flower imports (especially roses) now originate from Kenya. Dieldrin, DDT and endosulfan, used to control mosquitoes and tse tse flies, have now been replaced with organophosphorus compounds, carbamates and pyrethroids. For example, pirimiphos-methyl is used against adult mosquitoes outdoors and permethrin is sprayed in households to treat bed nets, curtains and fabric against mosquitoes and other biting insects. Niclosamide and trifenmorph have been used in the Mwea Tabere settlement scheme to control the water snail. Bromophos, dichlorvos, pirimiphos-methyl and malathion are the main pesticides used to treat stored grain, while a combined permethrin/piperonyl/dichlorvos aerosol formulation is sprayed to control crawling and flying insects, cockroaches, ants, houseflies and mosquitoes (Wandiga, Lalah and Kaigwara 2002).

By 1997, PCPB had registered 370 formulations (representing 217 active ingredients) for use in Kenya (Ohayo-Mitoko 1997; Wandiga, Lalah and Kaigwara 2002). Since its inception in the early 1980s, the Board has banned or restricted the use of a number of pesticides, most of them organochlorines (see Table 3.5).

Table 3.5 List of pesticides banned in Kenya by PCPB since 1997

Common name	Previous usage
DDT	Insecticide mainly for mosquito control
Dibromochloropropane (DBCP)	Soil fumigant
Ethylene dibromide (EDB)	Soil fumigant
2,4,5-T	Phenoxy herbicide
Chlordimeform	Acaricide/insecticide
All isomers of HCH	Insecticide
Chlordane	Insecticide
Captafol	Fungicide
Heptachlor	Insecticide
Toxaphene (camphechlor)	Acaricide
Endrin	Insecticide
Parathion (methyl and ethyl)	Insecticides
Aldrin, dieldrin[a]	Insecticides, mainly for termite control
Lindane	Allowed only for seed dressing

[a]No longer available in Kenya
Source: Wandiga, Lalah and Kaigwara 2002

The information reviewed in this section illustrates Kenya's longstanding history of intensively using toxic pesticides that have long since been prohibited in other countries to combat outbreaks of disease and pest populations that threaten human and domestic animal life. In the case of the rice industry, increases in production and pesticide applications have resulted in the resurgence of some insect pests (e.g., leaf hopper and plant hopper species, and whorl maggots and caseworms) and a decrease in others (e.g., stem borer species) (Heinrichs and Mochida 1984). The emergence of pesticide resistance in rice pest species has driven research and development of alternative pesticides and biocontrol technologies/strategies worldwide (Heinrichs 1981; Heinrich 1994). The use of indigenous predators, parasitoids and insect pathogens as well as the development of more resistant rice varieties are the cornerstone of modern integrated pest management (IPM) strategies. Such measures have reduced dependence on chemical pesticides such as carbofuran in many countries. Although the level of the research undertaken in Kenya may not yet have reached comparable dimensions, existing technologies involving IPM can provide alternatives to the use of carbofuran and other pesticides that menace non-target organisms and should be pursued as part of a viable pest control strategy.

Residues of organochlorine, organophosphorus and (more recently) carbamate compounds have also been detected in non-target species including domestic animals (e.g., cattle), fish, birds and people, often at levels of concern. Table 3.6 summarises various concentrations of pesticide residues detected in birds, fish and mammals (including humans) in Kenya from the 1970s to 2008.

The concern regarding carbofuran runoff into surface waters when the compound is applied in flooded irrigation schemes has nonetheless been raised (Moses, Johnson and Anger et al. 1993; Hutson and Roberts 1994; Lalah, Kaigwara, Getenga et al. 2001). The leaching potential of carbofuran in Kenyan soils has also been demonstrated (Lalah and Wandiga 1996a, b). The most

Table 3.6 Summary of various concentrations of pesticide residues detected in fish, mammals, and biological matrices reported in Kenya from the 1970s

Pesticide	Concentration range mg/kg ww	Reference
∑DDT, in fish and bird tissue, Lake Nakuru	$3.4-6.4\times10^2$	Koeman et al. 1972
DDT, β-HCH, dieldrin, heptachlor, man adipose tissue	nk	Wasserman et al. 1972
∑DDT, in fish (*Labeo gregori/Clarias gariepus*)	0.13−6.01	Munga 1985
∑endosulfan, in (*Labeo gregori/Clarias gariepus*)	0.004−0.090	Munga 1985
DDT, DDE, dieldrin, lindane, aldrin, in cattle fat bream	nk	Maitho 1978
DDT, dieldrin, in chicken eggs, Embu District	nk	Kahunyo et al. 1986
Dieldrin, aldrin, in game animals, Lambwe Valley	nk	Alsopp 1978
DDE, in bird tissue, Lake Nakuru	$4\times10^{-7}-4\times10^2$	Lincer et al. 1981
∑DDT, fish (*T. nilotica, Labeo cylindricus*), L. Baringo	0.009−0.40	Lincer et al. 1981
∑DDT, fish (*Spirilus nigrax, M. Salmonids*), L. Naivasha	0.001−0.003	Lincer et al. 1981
∑DDT, fish (*Tilapia grahami*), Lake Nakuru	0.015	Lincer et al. 1981
∑DDT, fish (*Lates nilotica*), Lake Victoria	0.004	Foxall 1983
β-HCH, in human milk, Nairobi hospital	$9\times10^{-6}-1.0$	Kanja 1988
DDT, in (*Lates niloticus*) fat and fillets, Lake Victoria	0.45−0.99	Mitemi and Gitau 1990
β-BCH, dieldrin, lindane, (*Lates niloticus*), Lake Victoria	$2.88\times10^{-4}-0.77$	Mitemi and Gitau 1990
∑DDT sharks, bream, catfish, Athi River	0.15−0.70	Mugachia et al. 1992
∑DDT, tilapia, catfish, common carp, Masinga Dam	0.113−0.234	Mugachia et al. 1992
Lindane, in tilapia, catfish, Masinga Dam	0.013−0.021	Mugachia et al. 1992
Chlorfenvinphos, in cow milk, western Kenya	*1.58−10.69 (fat)	Kituyi et al. 1997
∑DDT, β-HCH in fish Indian Ocean coast, Mombasa	1.2−323(dry fish)	Everaarts et al. 1997
DDT, in fish (*Tilapia zillii*), Tana River	[1]bdl	Lalah et al. 2003
∑endosulfan, (*Tilapia zillii*), Tana River	[2]bdl	Lalah et al. 2003
DDE, dieldrin, lindane, (*Tilapia zillii*), Tana River	*0.0018−0.141 (fat)	Lalah et al. 2003
∑DDT, in fish, Indian Ocean coast	$13.5-2.31\times10^2$	Barasa et al. 2008
∑endosulfan, in fish, Indian Ocean coast	5.9−55.0	Barasa et al. 2008
Aldrin, dieldrin, lindane, in fish, Indian Ocean coast	1.2−1.445×103	Barasa et al. 2008

Indian Ocean coast includes samples from Sabaki, Kilifi, Mombasa and Ramisi.
Indian Ocean fish include sardine (*S. Fambriata*), penaeus spp, black pomfret (*A. niger*) and silver carp (*P. Argenteus*). Fish fat content range; 0.22–8.59%; [1]bdl: below detection limit (<0.003 ng/g lipid), [2]bdl: below detection limit (<0.042 ng/g lipid); *concentration range based on $mgkg^{-1}$ lipid
nk: detected but concentration not given
ww: wet weight

likely route of exposure to fish, birds and mammals after legal application of the compound in soil would therefore be through water. In this regard, the application of carbofuran in flooded soil poses a great risk to birds that sift waterlogged sediment in search of food. Indeed, the application of carbofuran granules in flooded and partially flooded fields has given rise to many instances of waterfowl mortality (see Chapter 8). The lethality of carbofuran to aquatic birds during poisoning of ducks in the irrigation schemes at Mwea and Ahero was highlighted earlier in the 1990s (Odino and Ogada 2008a, b). Nonetheless, neither domestic water supplies nor aquatic and other wildlife species in these areas have been analysed to assess potential exposure to carbofuran. The next section reports on the illegal use of carbofuran to hunt birds in a rice settlement scheme for the purpose of human consumption, discusses the repercussions to avian biodiversity and considers the potential risks to human health.

3.3 Measuring the conservation threat that deliberate poisoning poses to birds in Kenya: The case of pesticide hunting with Furadan in the Bunyala Rice Irrigation Scheme

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3.3.1 Introduction

Poisoning is a latent and ruthlessly effective method of killing wildlife. In Kenya, pesticides are easily available and seen as efficient poisons to capture food for human consumption, in this case, birds. This is the phenomenon of 'pesticide hunting' practiced in my country. Our avian biodiversity is particularly vulnerable to such poisoning. Birds here are poisoned directly (for procurement of food and to eliminate species viewed as 'pests'), indirectly (through incidental and accidental poisoning), and secondarily (after consumption of other poisoned animals).

Kenya has the second highest avian diversity in Africa and the eleventh worldwide, boasting over 1 100 bird species, which is rather remarkable (Nature Kenya 2009; Mongabey 2010). Such diversity adds richness and value to the wildlife industry, which is Kenya's giant source of foreign income. Wetlands, whether natural or man-made, represent vitally important habitat to wildlife, particularly birds. A number of man-made wetlands in Kenya have been recognised as Important Bird Areas (IBAs). For example, the Dandora Oxygenation ponds in Nairobi (designated as KE IBA 35) are internationally recognised for their value to birds (Bennun and Njoroge 1999).

From a bird's perspective, irrigated fields such as those in the Bunyala Rice Irrigation Scheme are essentially man-made wetlands in which they may congregate to forage. Reports made in the early 1990s by Kenyan conservationists, particularly ornithologists, warned that wetland birds congregating in irrigation schemes were being hunted in large numbers, with pesticides (O. Nasirwa, personal communication). This is also in accordance with the author's own personal observations.

The study described here was initiated to investigate the extent of the deliberate poisoning of birds with pesticides in the Bunyala Rice Scheme, to quantify bird deaths, assess the implications of this practice to conservation, and highlight potential repercussions of consuming pesticide-poisoned birds to human health.

The specific objectives of the study were to:

1. Assess avian mortality as a result of deliberate pesticide baiting in the Bunyala Rice Scheme (during the study period).

2. Provide evidence to authenticate avian poisoning using pesticides at the study site.

3. Educate local communities on the dangers of pesticides (e.g., toxicity and misuse).

4. Inform government and NGO stakeholders on the outcomes of the study.

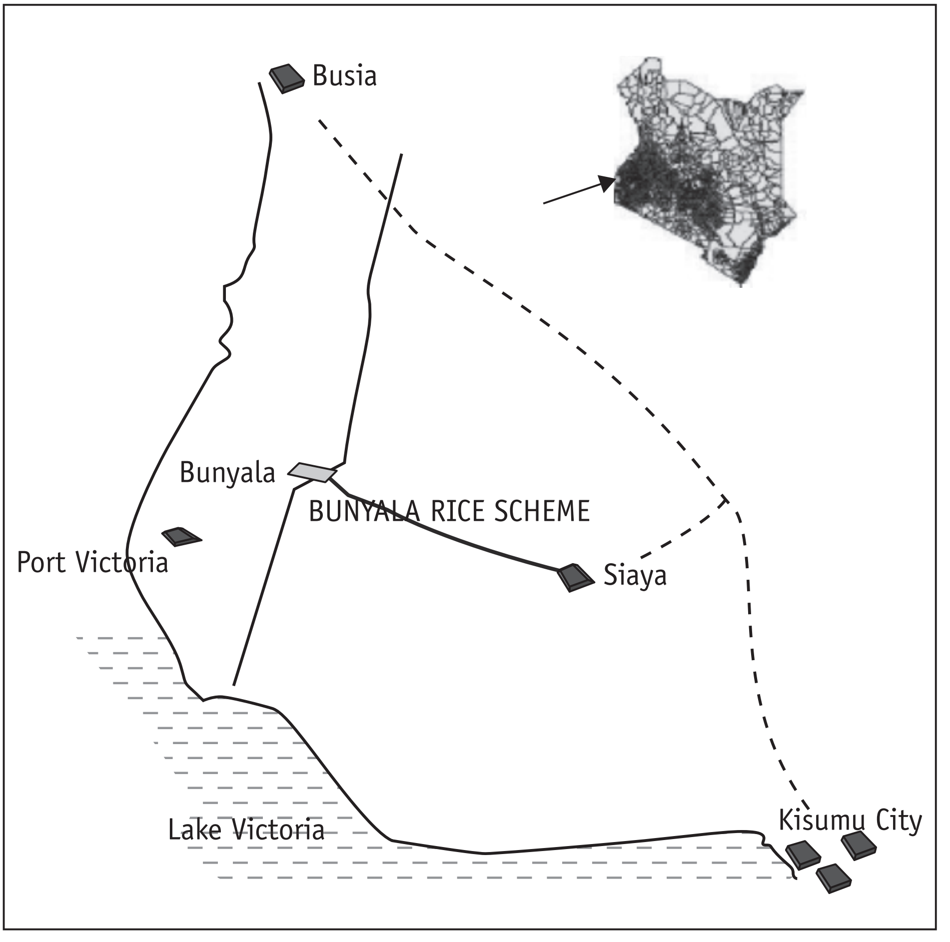

Figure 3.2 Study area and bird poisoning areas (detail) in Bunyala

3.3.2 Methodology

3.3.2.1 Study site and study area

The Bunyala Rice Irrigation Scheme (approximate central coordinates 00°05.797´N, 034°03.658´E) is located in Busia District, western Kenya. The study area encompassed an average radius of 5km around the irrigation scheme, which allowed us to establish the extensiveness of bird poisoning in Bunyala. The habitat is a dynamic man-made wetland; seasonally flooded at cultivation time and seasonally dry at harvesting time until the next period of cultivation. The study site spanned approximately 1 000 hectares of the main farmland and another 500 hectares of disjointed, smaller satellite farmlands. Figures 3.2 and 3.3 illustrate the distribution of poisoning in Bunyala (Magombe East and West). Figure 3.3 also indicates that other than a few outlying points to the east and south, the main rice scheme was the site of the majority of the poisonings.

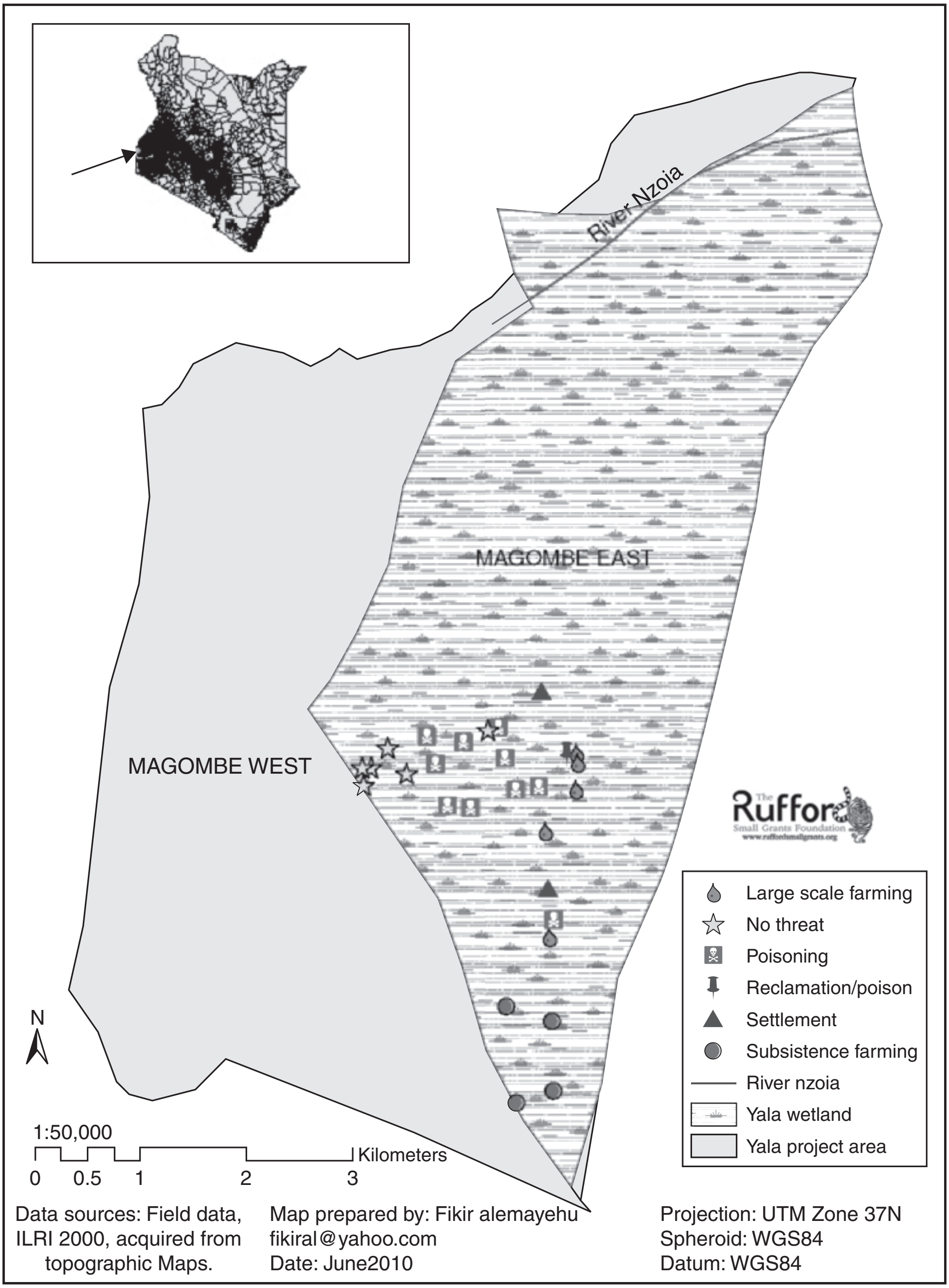

Figure 3.3 Study area and bird poisoning areas (detail) in Bunyala

3.3.2.2 Methods

Field work was conducted on site, between February and December (2009).

1. Stratified sampling survey

   The Bunyala rice plantation itself is large, but it has been subdivided into small rectangular plots, which served as the individual grids on which samplings and observations were made during the study. Each plot was delineated by soil embankment and occupied an average area of 0.75 acre. Grids were selected for sampling following opportunistic observation of pesticide poisoning there. Targeted bird species were partially identified on the basis of the type of baits set out. The number of targeted species was then recorded between the time that poachers put out the bait in the plot(s) and the time that the carcasses of the poisoned birds were gathered.

   Individuals that flew in during the 'waiting period', i.e., the duration that a poacher kept away from the quadrant where bait had been laid (and also that passersby were directed to keep off the poisoning site), were added to the total already recorded. This total represented the observed sample for each of the species. The individuals that flew out during this same 'waiting period' were included in the number observed since they too were assumed to be possible victims of intoxication. Once a poacher had gathered his kill, we approached and asked if we could identify and record each of the species killed. In some instances we had to estimate species from a distance to avoid unwelcome aggression from the poachers.

2. Questionnaires and interviews

   We sought permission from locals to survey them, explaining that we needed information about the bird poisoning industry to plan for the educational component of the study and to identify potential alternatives to the practices of poaching and consuming the flesh of poisoned birds (since we believe that both pose risks to human health). Two kinds of questionnaire were then administered for different respondent groups:

   (a) Poacher/hunter questionnaire: administered to those who poisoned birds, to obtain information regarding the manner of poisoning and to assess their attitudes towards their way of life.

   (b) Consumer questionnaire: targeted members of the general public who purchased poisoned birds/carcasses from poachers.

   The questionnaire was administered a second time, targeting individuals not approached during the first phase of the study, to evaluate the level of awareness and the effect (if any) of our attempts to 'educate'. Additional information was also obtained during informal question and answer sessions.

   ii. Thin Layer Chromatography (TLC) analysis

   A selected number of bird carcasses (n = 10, including one bait sample) were collected from the poisoning field while others were purchased directly from the poachers, (to avoid bias), for laboratory testing. Nine avian carcasses were eviscerated (i.e., the guts were removed), stored in glass tissue jars then kept frozen on ice in a cool box and transported to Nairobi for carbamate analysis (using TLC) at the Government Chemist Laboratory. A sample of the pesticide-laced rice bait/granules collected from the container in which the poacher's bait was stored was also tested.

3. Educational component

   The educational component of the study was conducted to enhance local people's appreciation of birds and their knowledge about pesticides, particularly Furadan, which had previously been established as the product of choice to poison birds in an earlier study, and during preliminary interviews and physical examination of poison baits for this study. Two local scouts were trained to identify and count (poisoned) birds, and to estimate the numbers in large flocks. The author, with the assistance of the two scouts, also educated other locals on the potential repercussions of Furadan to people and wildlife, mainly during

informal sessions. The opportunity always presented itself whereby a few individuals became interested in learning what the project was all about and in the end the relevance of the project was presented to the gathered multitude.

4. Periodic reporting and blogging

   Monthly updates on the bird poisoning as it unfolded at the study site were provided to the Pest Control Products Bureau (PCPB) between March and July 2009. The activities related to the project and immediate findings were documented via a blog (http://stopwildlifepoisoning.wildlifedirect.org/). The aim of disseminating information through this popular form of online advocacy was to increase publicity and raise awareness of the issue with the general public, both locally and internationally. The blog also provided a means to share anecdotal information and catch the attention of government pesticide regulation authorities regarding the use of Furadan to deliberately poison birds both at the study areas and elsewhere (particularly other rice irrigation schemes) where there is a similar problem.

3.3.3 Results of the study

First, it was established that Furadan was used extensively to poison birds in the Bunyala Rice Irrigation Scheme. Furadan is often referred to as '*dawa*', which means a drug equivalent to a poison. In Bunyala, they call it '*dawa ya ndege*' (a poison for birds), even though it was initially introduced here for use in the rice plantation.

Our findings were obtained during ten-day monthly field surveys carried out from March 2009 to December 2009. Most of the data obtained was gathered by the PI and the Project Assistant (PA). Additional data obtained by the two local assistants, though less rigorous, was also incorporated. The percentage mortality threat was not calculated for birds that were collected by poachers but whose initial (live individual) totals were not estimated, which tended to occur when there were large flocks of mixed species. All poisoned individuals that were actually observed in an incapacitated state were documented. In some cases, poachers dislocated the wings and limbs of intoxicated birds to immobilise and prevent them from flying away in case they recovered. Still alive but clearly disoriented, these birds were then used as bait, to attract others of the same species.

Various food baits were laced with Furadan to lure and poison birds. Snails and termites (sometimes still alive) and small fish were laced with purple granules or powder from ground granules, while rice was soaked in a (purple) pesticide solution. Initially, the purple-blue granules were almost insoluble in water, but with stirring the solution became the colour of the granules. Poachers used stirring sticks (as shown in Figure 3.4) to prepare the solution and deemed it ready for use once it became a certain colour of purple, which they judged by eye.

By our estimation, poachers tended to use approximately one tenth of a teaspoon of granules in each individual snail bait, which they then used to lure snail-eating birds, particularly the African openbills (*Anastomous lamelligerus*). The birds needed only to ingest about three snail-baits (see Figure 3.5) to become very weak. Any remaining bait was then 'recycled' to poison other birds. Small birds like sandpipers took about one minute to get 'wobbly', whereas larger birds such as storks could take ten minutes before being similarly impacted. This observational component was one of the most difficult parts of my study, to see birds broken and dying, to love birds and not be able to help them because it was necessary to maintain objectivity for the study and avoid bias.

3.3.3.1 Results of bird mortality by pesticide poisoning

Overall, 3 186 victims of Furadan poisoning were documented (see Figures 3.6 and 3.7). This is out of the total 8 659 individual birds that were observed visiting the field plots in the irrigation scheme, and represents a 37% mortality rate, across 32 species. Four hundred and fifty two (452) of 1 005 palaearctic

Figure 3.4 Poacher mixing poison for baits by hand
Photo taken by Martin Odino

Figure 3.5 *Pila ovata* snails used for baiting the African openbill (*Anastomous lamelligerus*). Poison granules appeared as purple-blue in the cavities of the snail shells
Photo taken by Martin Odino

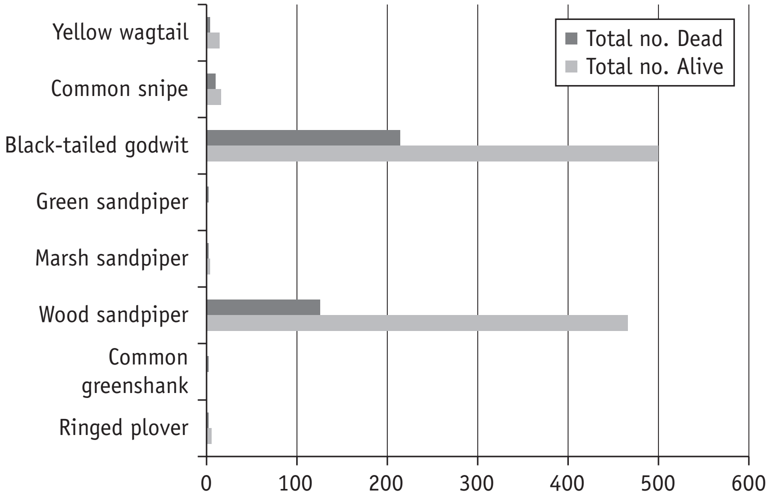

Figure 3.6 Observed palaearctic migrant bird visitors/mortalities per monitoring plot

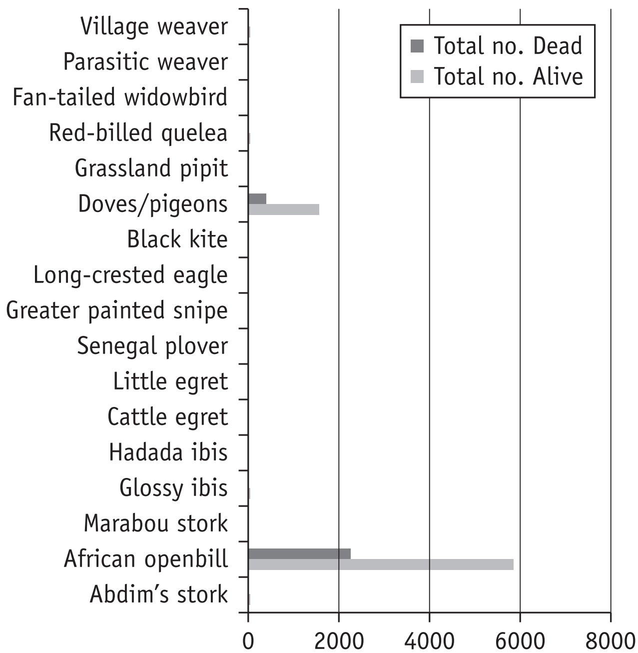

Figure 3.7 Observed resident and intra-African migrant bird visitors/mortalities per monitoring plot

Table 3.7 Results of observed cumulative palaearctic migrant bird mortalities in all quadrants (plots)

Species	No. alive	No. dead	Percent mortality
Ringed plover	5	2	40
Common greenshank		2	
Wood sandpiper	467	126	26.98
Marsh sandpiper	3	2	66.7
Green sandpiper		1	
Black-tailed godwit	500	215	43
Common snipe	16	10	62.5
Yellow wagtail	14	4	28.57
Ruff		3	

Table 3.8 Results of observed cumulative resident and intra-African migrant bird mortalities

Species	No. alive	No. dead	Percent mortality
Abdim's stork	29	26	89.69
African openbill	5848	2261	38.66
Marabou stork	10	3	30
Glossy ibis	39	6	15.38
Hadada ibis	6	1	16.67
Cattle egret	21	9	42.86
Little egret	8	3	37.5
Senegal plover		4	
Greater painted snipe	4	1	25
Long-crested eagle		2	
Black kite		1	
Doves and pigeons	1570	391	24.9
Grassland pipit	2	1	50
Red-billed quelea	50	12	24
Fan-tailed widowbird	11	8	72.72
Parasitic weaver	6	4	66.67
Village weaver	50	2	4

migrants were lost, representing an annual rate of 45% mortality. In addition, 2 734 of the observed 7 654 intra-African migrant birds were poisoned, which represented a mortality rate of nearly 38%.

The analysis that follows examines the impact of poisoning (and the subsequent population decline) on palaearctic migrants, birds that winter in Africa from Europe; e.g., wood sandpiper (*Tringa glareola*), black-tailed godwit (*Limosa limosa*) and the intra-African migrants which move within Africa, including the African openbill, Abdim's stork (*Ciconia abdimii*) and glossy ibis (*Plegadis falcinellus*). The comparative mortality within species (mortality against total numbers) and individual species losses (percentage mortality rate) are tabulated in Tables 3.7 and 3.8.

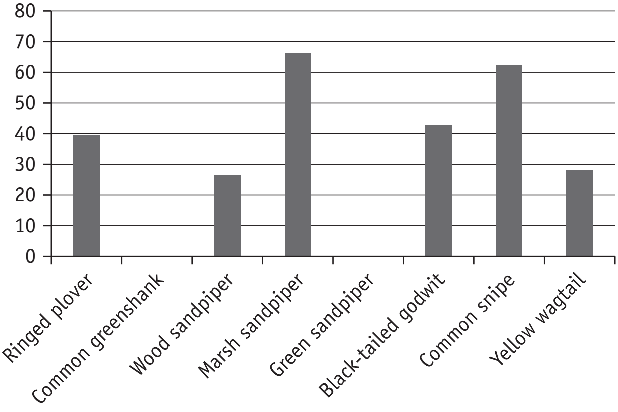

Figure 3.8 Percent mortality of palaearctic birds

The highest mortality amongst palaearctic migrants was noted in the black-tailed godwit: 215 of 500 observed individuals succumbed to poisoning. Wood sandpipers were the second most poisoned palaearctic bird, with 126 of 467 individuals poisoned. The green sandpiper (*Tringa ochropus*), marsh sandpiper (*Tringa stagnatilis*), common greenshank (*Tringa nebularia*), ruff (*Philomachus pugnax*) and ringed plover (*Charadrius hiaticula tundrae*) were poisoned in comparatively smaller numbers (less than 100 individuals) but they are also less abundant. From these results we concluded that the number of palaearctic individuals killed by poisoning is directly proportional to the flock or group size of the species.

As shown in Figure 3.8, mortality rate expressing percentage losses per species was highest in marsh sandpipers followed closely by the common snipe (*Gallinago gallinago*), black-tailed godwit, ringed plover, yellow wagtail (*Motacilla flava*) and finally the wood sandpiper. Percentage mortality in this case was highest in less common (or abundant) species. The values presented in Table 3.7 show that the wood sandpiper was the second most killed species, but suffered the lowest mortality rate. In contrast, the marsh sandpiper endured 'negligible' total mortality but suffered the highest mortality rate (Table 3.7). This indicates that the less common species were more adversely affected.

Table 3.8 summarises mortality against total numbers observed for resident and intra-African migrant bird species. Of the resident and intra-African migrants, the African openbill was by far the most poison-killed species. Two thousand two hundred and sixty one (2 261) of 5 848 individuals exposed to poisoning died. In fact the openbill suffered the highest mortality from poisoning overall, accounting for 26% of all mortality observed at the site. Mixed species of doves and pigeons were the second most poisoned bird family (391 of 1 570 poisoned). These species were lumped together because they associated closely and distinguishing one from another was difficult. The Abdim's stork was the third most poisoned species while the rest followed regressively with mortalities of less than ten individuals each. As was the case for the palaearctic migrants, the most abundant intra-African migrant species were also the most poisoned.

The African openbill was poisoned using a 'unique' baiting technique that employed live decoys whose beaks were fastened with string or a rubber band (to prevent them from eating the poison laced bait (*Pila* sp. snails)) and whose feet were tied to restrict movement. The poachers went around disturbing nearby flocks of openbills which then only had the option of settling around the decoys and baits otherwise the disturbance went on and on. This practice increased the incidence of openbill poisoning.

In Bunyala (and undoubtedly elsewhere) decoy birds are captured and kept to lure other birds of the same species (see Figure 3.9). The presence of the decoy suggests to the unsettled birds that there

Figure 3.9 Live openbill decoys and poisoned victims
Photos taken by Martin Odino

is a food source, and many flocks are fooled. Birds in the best body condition, with minimal injury, are selected from a poacher's catch as decoys. Poachers then carry the decoy birds home as part of their 'hunting gear' and back to the killing grounds during the next poisoning exercise.

The percentage mortality rate of each of the poisoned resident and intra-African migrant birds was calculated and plotted (Figure 3.10). Abdim's stork had the highest mortality followed by fan-tailed widowbird (*Euplectes axillaris*), parasitic weaver (*Anomalospiza imberbis*), grassland pipit (*Anthus cinamomeus*), cattle egret (*Bubulcus ibis*), African openbill, little egret (*Egretta garzetta*), Marabou stork (*Leptoptilos crumeniferus*), greater painted snipe (*Rostratula benghalensis*), red-billed quelea (*Quelea quelea*), Hadada ibis (*Bostrichia hagedash*), glossy ibis (*Plegadis fulcinellus*) and village weaver (*Ploceus cucullatus*). Eight of 11 fan-tailed widowbirds were poisoned, giving them the second highest rate of mortality. The African openbill had the highest mortality rate.

Results of questionnaires and interviews

Thirteen questionnaires were administered to poachers and 207 (62 at the start of the study and pre-education stage; 180 at about the end of the study) to consumers.

Poachers' responses

Five poachers were interviewed at both the pre- and post-education stage of the study, and an additional four were interviewed at the end of the study (one of the poachers initially interviewed, who was between 60 and 70, quit poaching to become a herder, purportedly due to old age). Poachers hunted birds in teams and so the additional four poachers might simply have given the same information as that obtained from the four already questioned during the pre-education stage. Nonetheless they were interviewed to evaluate any ideological differences that might exist amongst the teams.

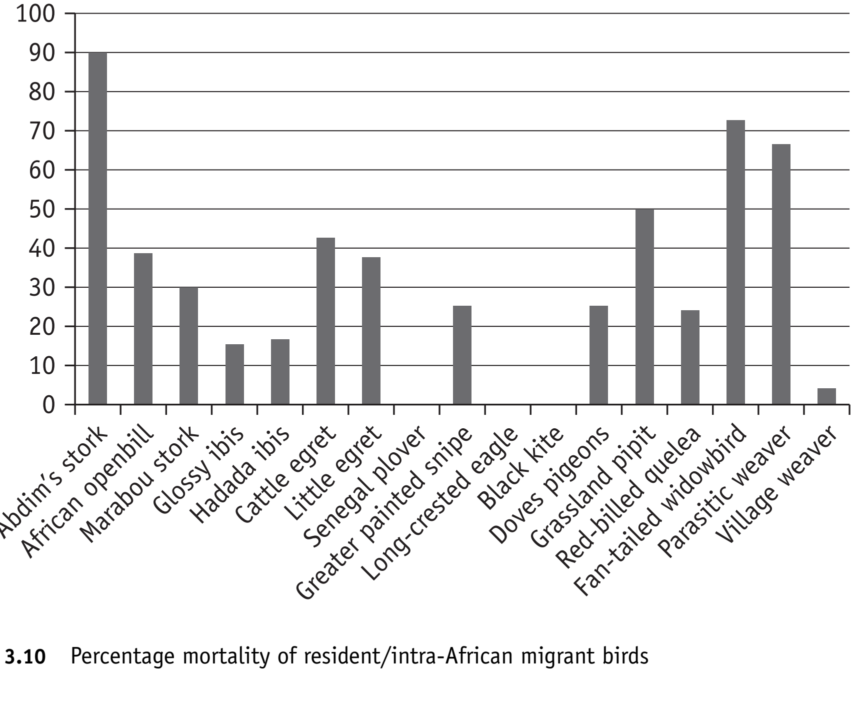

Figure 3.10 Percentage mortality of resident/intra-African migrant birds

All eight poachers had been poisoning birds for more than five years. Five of the poachers claimed that poaching birds was their sole source of income. Every poacher named Furadan as their poison of choice. Two of the poachers indicated they had attempted to use a silvery granulated compound that had replaced Furadan during July 2009. From their description we suspect that the pesticide in question was Mocap (which contained the organophosphorus compound ethoprop). Both stated that the compound was pungent and repelled rather than poisoned the birds. Further, this other pesticide gave the poachers respiratory problems, which they did not appreciate.

All the poachers stated they were aware of the toxicity of Furadan. However, they also claimed that washing their hands and specially preparing the carcasses before eating eliminates any residues of carbofuran. Indeed, once a bird is poisoned, the entrails are removed, the bird is hung to drain the fluids then it is slow heated and partially roasted in the traditional manner, as with animals killed with poisoned arrows. After this process, the birds are cooked and eaten. Poachers interviewed during the second phase of interview (after we had conducted the educational component) knew that Furadan affects the central nervous system. Despite this, all still held firmly to the belief that draining/heat treatment prior to consumption 'detoxified' a carcass.

During the first phase of questionnaire administration, some of the poachers said their poaching frequency varied, depending on need. They stated that they would poison daily, especially during the rice planting season (which varies depending on the rains). One specialist poacher who targeted doves and pigeons stated that he poached seasonally, during the two months or so that rice was harvested, when the number of birds in the irrigation fields was greatest. At other times he made his living as a self-trained electronics repairman. The fifth poacher said he poisoned birds daily.

Four of the five poachers stated that they poisoned the African openbill as a priority, but also waders and seedeaters if the wild storks had become imprinted against, or habituated to, the decoy birds. The fifth poacher focused on poisoning doves and pigeons, but like the rest also poached waders and seedeaters opportunistically. Specialising in baits and species reduces conflict, because even if intoxicated birds crossed into adjacent poisoning 'territories', poachers tend to respect the fact that it is another's quarry, providing it is not the same species they are targeting. In that case, disputes between poachers arise for quarry. All five respondents used the same cost scale for poisoned birds, i.e., highest prices for larger birds such as openbill, and lower prices for the smaller waders and seedeaters (e.g., pigeons, doves, pipits, widowbirds, weavers), as summarised in Table 3.9.

Due to the adverse publicity from the international community and a resultant (attempted) buyback by FMC, the manufacturer, the price of Furadan rose sharply during the study period. In the first part of the study, while the chemical was still readily available, it cost approximately 100 Kenyan Shillings (1.25 USD) per 200 gram pack. At the end of the study the product was not easily available and the price had risen to approximately 800 KSh (10 USD) which resulted in a corresponding increase in the prices of preferred species (African openbill, doves/pigeons, sandpipers, widowbirds/weavers/pipits). The reader will note that even with the price hikes, the cost of bird meat ranged from a value of 0 to approximately 5 USD.

Consumers' responses During the first phase of the questionnaires/interviews, two respondents stated that they ate wild bird meat daily; one was the wife of a poacher and the other was a primary school class 6 child (aged approximately 11). Sixty consumers responded that they purchased bird meat opportunistically, when the poachers/vendors came by with the meat or when they found it for sale at the local market. In the second phase, 112 respondents out of 180 stated that they purchased bird meat opportunistically whereas 68 refused to answer the question of how frequently they consumed birds. None said that they fed on poisoned bird meat because no other source of protein was available, which was among the options provided in the questionnaire.

In the first phase of questionnaires/interviews, 19 of 62 consumers (i.e., 31%) stated that they preferred bird meat to other sources of protein while in the second phase 29 out of 180 (i.e. 16%) preferred it. All the respondents were also aware that the birds were obtained from the wild and poisoned with Furadan, but they maintained that draining fluids from the carcasses by slow roasting

Table 3.9 Bird meat price list per individual unit (in KSh and USD[a])

	Phase I of interviews/ questionnaires		Phase II of interviews/ questionnaires	
Species/family	Raw KSh/USD	Dried/Roasted KSh/USD	Raw KSh/USD	Dried/Roasted KSh/USD
African openbill	50/0.60	70/0.87	80/0.99	100/1.2
Marabou stork	400/4.97		400/4.97	
Ibises and egrets	40/0.50		40/0.50	
Pigeons and doves	20/0.25	40/0.50	40/0.50	50/0.60
Sandpipers	10/0.1		20/0.25	
Widowbirds/ weavers/pipits	5/0		10/0.1	

[a]1 USD = ca 80 KsH

or hanging the carcasses over glowing firewood embers before cooking 'detoxified' the flesh/carcasses. Nonetheless, they acknowledged that the pesticide being used, Furadan, was deadly toxic. In a sidenote, a woman in Bunyala was reported to have used Furadan to poison her husband and her children for her husband's infidelity. In fact, Kenyan women are rarely allowed to purchase pesticides from an agrovet's shop because of the fear that they will use it to poison a husband who has been unfaithful.

The consumers interviewed also stated that they ate many of the species shown in Table 3.9. However, the African openbill and the doves/pigeons were clearly favoured, having been named by 219 of the 242 consumers (i.e., 90%). It is also worth noting that while all 62 respondents in the first interview phase freely answered the question regarding which birds they consumed, 23 out of the 180 respondents (i.e., 13%) would not respond in the second phase. The consumers reported that they had no particular supplier but could obtain wild bird meat by placing an order with any of the poachers to supply them. The prices quoted by consumers matched that shown in Table 3.9.

3.3.3.2 Results of Thin Layer Chromatography Analysis

Presence of a carbamate (i.e., carbofuran) was detected in the sample labeled 'BAIT' which was recovered from one of the jars used by a poacher to prepare his bait. The same results were consistent in the 'GUT' samples 1, 2, 3 and 7. No other chemically toxic substances were detected in the 'GUT' samples.

3.3.3.3 Impact of education and awareness on Furadan poisoning

Education was used as a tool, to empower locals in the study area and change their perspectives about poisoning and eating intoxicated birds. Two local assistants were trained for this purpose. Although the study has now been completed, these individuals remain involved in monitoring poisoning activities and recruiting others to join the local bird watching team, which also advocates against bird poisoning (see Figure 3.11).

Informal and opportunistic sessions were conducted with both poachers and consumers, to generate awareness about the risk that Furadan and other compounds may pose to human health. However,

Figure 3.11 Poachers being educated about birds and their values
Photo taken by Martin Odino

we were confronted by the widely held and virtually unshakeable belief that Furadan-poisoned bird meat is 'detoxified' by roasting or hanging prior to consumption.

Since no human mortality cases that could be directly linked to pesticide poisoning have yet manifested themselves, the locals were not appreciably convinced that consuming birds poisoned with Furadan was significantly harmful to them. We were often told that 'nobody reads the labels' and, if we told anyone (poachers included) that they should not touch the compound with their bare hands they essentially said: 'we have been touching it since before you were born and we are not dead yet'. Nonetheless, some poachers were persuaded to change to vegetable farming, using the abundant water resource from River Nzoia and receding waters of the customary annual floods in the area after the PI (M. Odino) enumerated the advantages of farming over poaching.

Regular blogging on the WildlifeDirect platform at http://stopwildlifepoisoning.wildlifedirect.org/ and http://baraza.wildlifedirect.org/ as the study progressed helped raise the international profile and visibility of this issue. The timing of the study also coincided with the airing of the '60 Minutes' segment on a major American television network and the subsequent buy-back offer by FMC, the manufacturer of Furadan.

While the product is now scantily available in most agrovet shops, it remains available both in Kenya and adjoining countries. Monthly updates on Furadan-associated bird mortality at the study site were made available to other stakeholders, namely the Kenyan Wildlife Service (KWS), Nature Kenya (Birdlife International's local partner), Crop Life Kenya (formerly Agrochemicals Association of Kenya (AAK)) and the PCPB. Talks between conservationists, particularly WildlifeDirect, and PCPB following a government ministerial (Agriculture) directive to look into the case are underway in an attempt to better regulate Furadan and other potentially deadly pesticides. Unfortunately, this venture does not seem to have moved forward very much.

3.3.4 Discussion

A significant proportion of mortality was observed in birds that visited plots where pesticide-laced baits were placed; 36% of all birds that visited the plots in which pesticide-laced baits were left in the irrigation scheme were killed. As such, it is entirely fair to say that the populations of a number of intra-Africa and palaearctic species are currently being decimated. The black-tailed godwit, for example, was listed in 2010 as Near Threatened by the IUCN (http://www.iucnredlist.org/apps/redlist/details/143984/0).

The Bunyala Rice Irrigation Scheme is located on a major migratory flyway, which means that unless the poisoning is addressed, populations will continue to decline. Wetland birds, including storks, egrets and waders, are the primary victims of deliberate poisoning. Grassland birds and birds of prey are attracted by the concentration of food resources at the rice irrigation plantation, and their numbers suffer accordingly. Only frugivorous birds were not affected at this study site.

Flocking birds were the primary target of pesticide hunting of all the species poisoned (i.e., 87.5%, or 28 of 32). Jointly, four species of raptors and non-flocking birds were also casualties of poisoning: long-crested eagle (*Lophaetus occipitalis*), black kite (*Milvus migrans*), yellow-throated longclaw (*Macronyx croceus*) and grassland pipit (*Anthus cinnamomeus*). The African openbill, doves/pigeons (see Figure 3.12), black-tailed godwit and wood sandpipers (see Figure 3.13) were the most frequently killed species.

Occurrence (seasonality) also determined the intensity of poaching, and therefore, the level of mortality. Overall, resident species suffered higher mortality rates. The African openbill endured the heaviest mortality because it is a flocking species and is also present year round at the site. Hunting this species is enhanced using decoy methods of baiting leading to a very high mortality of the species. These factors likely made the openbill the bird of choice amongst poachers and consumers over time. Considering its size, the openbill stork is sold at a very low price and as a result, it is preferred

Figure 3.12 Mixed species of doves being gathered from the poisoning field
Photo taken by Martin Odino

Figure 3.13 Poisoned wood sandpipers (*Tringa glareola*)
Photo taken by Martin Odino

by most consumers and killed in large numbers. The Marabou stork is sometimes referred to as '*mbuzi*', (i.e., the 'goat') because it is such a large bird.

Most other resident and intra-African birds are seasonally abundant (i.e., only found within the irrigation scheme when there is a crop). This was particularly the case for the doves and pigeons, which only flocked to the irrigation scheme at harvest time. Likewise, the palaearctic migrants are only seen in winter, since their breeding grounds occur in the northern tropics. However, certain palaearctic migrants are especially susceptible to poisoning, despite the short duration of their seasonal occurrence. Incoming palaearctic migrants are particularly vulnerable because they arrive hungry and will gorge themselves at stopover sites such as Bunyala. The black-tailed godwit suffered very high mortality rates (of 43%) after feeding on laced bait. This migrant species was only observed at the site at the in-coming stage (August to December) of migration and not during the return (early in the year when the study began in February and lasted until May) when it probably follows a different return route. In contrast, the wood sandpipers occurred both at the in-coming and return migrations, but suffered lower casualties than the godwit.

Some species were very easily poisoned with pesticides. For example, the Abdim's stork was readily drawn towards the bait and continued consuming poison-laced bait even if they saw other members of their flock becoming intoxicated and disoriented. By contrast, the open-billed stork is warier, and is alerted by the apparent intoxication of flock members. As such, repeated baiting sessions were sometimes required to kill this species.

Cultural practices and beliefs have entrenched the practice of poisoning birds in Bunyala. Even so, the problem may be more to do with attitude than culture. Many people believe that God has given what is in the wild to the people, and they will even point to passages in the Bible to justify their behaviour. People will often see a wild animal such as a baboon or wild boar and exclaim '*kitu mbaya*', meaning: 'the thing is bad'. Thus we seem to have an attitude problem towards our wildlife, associating certain wild animals with wickedness, when it is we who are wild towards them.

The questionnaires and interviews revealed that Furadan was the pesticide of choice and may still be in use at the study site. Toxicological assessments of baits and tissues from dead birds confirmed the presence of a carbamate. All of the poachers and consumers interviewed knew about (and supported) the practice of bird poisoning. Between 15 and 30% of the consumers stated that they preferred wild-caught bird meat to other sources of meat, claiming that it is tastier and more nutritious. This motive to consume birds that have been killed with pesticides is so strong that it overrides any knowledge of the dangers of potential secondary poisoning. The market for poached meat is large and has thus far been responsible for creating the demand that drives the poaching.

We documented a general lack of awareness/concern regarding risks of human pesticide poisoning from the practice of poaching and from consuming flesh of intoxicated birds. The people of Bunyala (poachers and consumers) hang and roast poisoned bird carcasses prior to consumption. As such, they feel the flesh of poisoned birds is safe to eat and claim to feel no ill effects. However, a poacher's wife (who claimed she ate poached bird meat every day) died early in 2010 from unknown causes, and we cannot help but wonder whether long-term exposure to pesticide-killed birds played any role. During our interview, she was nursing knee joint paralysis and was using a walking stick. This caught our attention because in the Mwea irrigation scheme (in central Kenya), they cook pesticide hunted birds fresh (rather than roasting or draining first), and many adults complain of knee joint pain.

Bird poisoning in Bunyala is already having a significant impact on local and migratory bird populations and may have already wiped out a number of local duck species populations. Bird poisoning at Bunyala has been going on for three decades at least, and information from locals indicates that initially wild ducks were mainly targeted. These include the whistling ducks (*Dendrocygna sp*) (J. Achieno, personal communication). Presently, very few of the ducks remain at the site and on many surveys none were observed (M. Odino, personal observation). In other irrigation schemes (i.e., Ahero and Mwea), where there were also surveys to record the incidence of bird poisoning, duck species were targeted. We suspect that the poisoning of wattled starlings (*Creatophora cinerea*) in Bunyala may have reduced the population to very small numbers since large flocks of this species, which were commonly seen with cattle about two decades ago (J. Achieno, personal communication), are sadly now a thing of the past.

Red-billed oxpeckers (*Buphagus erythrorhynchus)* also seem to be declining but this is more likely because of the intensive acaricide use, many of which should not be used for tick control. At one time it was common to see oxpeckers hanging from the ears of cows (to remove the ticks) but farmers chased them away and treated the cows with acaricides instead. Long-tailed nightjars (*Caprimulgus climacurus*) have recently been observed in the Bunyala area, which is very special because they have never before been reported here. But under the present circumstances and conditions they are likely to be forced out, and where else can they go to be safe? They will be lost before anyone even knew they were here.

3.3.5 General conclusions

The very high rate of bird poisoning in the Bunyala Rice Irrigation Scheme, using Furadan, is primarily driven by the demand for wild bird meat by the local population. The practice of pesticide hunting in this scheme poses a double threat in Kenya and to Kenyans. First, important bird populations are at risk and populations of at least two species have been altered significantly, perhaps irreversibly at the present rate of poisoning. Secondly, the regular consumption of bird flesh that has been procured using pesticides exposes consumers to potentially lethal concentrations.

Deliberate poisoning of birds is impacting on populations of both migrant and resident bird species. The most significantly affected species is the African openbill. During a good proportion of the study period (i.e., May to November 2009) the availability of Furadan was limited following its withdrawal from Kenya by the manufacturer FMC. We suspect that the mortality figures that we have reported here are lower than for previous years when the product was widely available.

In Bunyala, the practice of consuming wild meat does not arise from a lack of alternative protein. The practice has become a habit nurtured by the belief that wild-caught meat is best (and it helps that such meat is also less expensive than the alternatives). Local inhabitants of Bunyala are moderately successful domestic animal farmers who keep a modest number of livestock animals, including chickens, but they only eat these on special occasions. We also found that bird poachers were willing to abandon poaching for farming if provided with initial financial support to start vegetable growing and other legal businesses. However, poaching and consuming wild (bird) meat as a way of life remains deeply ingrained in people.

3.4 The role of carbofuran in the decline of lions and other carnivores in Kenya

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3.4.1 Background information

African wildlife populations have been in decline since European colonisation in the 1800s. Ever-increasing numbers of humans have destroyed habitat through conversion to agriculture and overgrazing by domestic livestock, and wild grazers have been decimated by the bushmeat trade. Large carnivores are usually the first species to disappear when humans expand into wild areas, killed in retaliation for depredation on livestock (Woodroffe 2001).

As pastoralist populations increase in arid and semi arid rangeland ecosystems, cattle, goats, sheep and camels replace native wild ungulates which are the normal prey of lions (*Panthera leo)*, leopards (*Panthera pardus*), cheetahs (*Acinonyx jubatus),* spotted hyenas (*Crocuta crocuta),* and wild dogs (*Lycaon pictus*). The predators turn to livestock and are poisoned, speared or shot. Although there are no reliable data for earlier periods, until recently conservationists estimated a continental population of 100 000 to 200 000 lions (Myers 1975; Nowell and Jackson 1996), evidence that they were still widespread and common. By today's best estimate, fewer than 30 000 wild lions remain in Africa, most of them in six very large national parks or managed areas (IUCN 2006). Most other protected areas are too small to protect viable populations of wide-ranging animals, as they move beyond park boundaries and come into conflict with people. In Kenya today, we believe lion numbers to be well below 2 000. Outside of national parks, it is rare to find tracks or hear them roaring.

Large carnivores have been in conflict with man over livestock depredation since ungulates were first domesticated by pre-agricultural humans. Traditional livestock husbandry systems prevent most depredation losses through close herding by day and enclosing livestock in thornbush bomas (i.e., enclosures) at night to prevent them from wandering (Ogada, Woodroffe, Oguge et al. 2003; Frank, Woodroffe, Ogada et al. 2005; Woodroffe, Frank, Lindsey et al. 2007). However, depredation losses can represent a considerable threat to the livelihoods of both traditional pastoralists and

commercial ranchers, and chronic problem lions are typically hunted and killed. Lions and hyenas are nocturnal, especially where persecuted by man, and when they kill a large animal, they return to finish it the following night.

In Laikipia District, commercial ranchers normally remove problem lions by 'sitting up' over a cow carcass killed by lions and shooting the animal which returns to feed. Traditionally, Maasai pastoralists dealt with lions by spearing, either in *Olkiyoi,* retaliation for a specific depredation in which any men may participate, or in *Olamayio*, a traditional ritual of young warriors (*murran)* associated with entering manhood (Hazzah, Borgerhoff Mulder and Frank 2009) that gains the successful warrior lifelong prestige. These methods require effort and skill, and often entail considerable personal risk. In social species such as lions and spotted hyenas, the individual specifically responsible for depredation is usually difficult to determine, but shooting or spearing tend to be specific and usually target the group of animals that made the kill (Woodroffe and Frank 2005).

3.4.2 Use of poison to kill carnivores in Kenya

Although there is no prestige associated with its use, poisoning a carcass is a risk-free and efficient method for removing predators. Lions are among the easiest to poison because they are considerably less wary and elusive than leopards or hyenas (Hazzah 2006; Hazzah, Borgerhoff Mulder and Frank 2009). In the twentieth century, both strychnine and toxaphene (an organochlorine used for 'dipping' cattle to prevent tick-borne diseases) were widely available and used for killing predators (Denney 1972). When strychnine was better controlled and toxaphene was replaced by acaricides with low toxicity to mammals, pastoralists discovered that carbofuran (sold as Furadan 5G) was highly effective for killing predators, very cheap, and universally available in Kenya: one could go into most agrovet in any small town, ask for something to kill predators or feral dogs, and be sold a jar of Furadan granules for 120 to 150 Kenya shillings (1.50 to 2.00 USD). Conservationists started reporting increasing numbers of predator poisoning incidents around the turn of the current century, accompanied by a decline in lion observations outside protected areas (Frank, in press). As described in Section 3.5, incidental mortality of vultures and scavenging eagles was enormous, and as a result, some species of vultures have virtually disappeared from Kenya, while others have become rare.

In response to adverse publicity in the United States, FMC Corporation withdrew Furadan from Kenya in 2009 and attempted to buy back remaining stocks from shops; there have been fewer reports of predator poisoning subsequently. However, carbofuran remains readily available in neighbouring countries and lions in Kenya continue to be poisoned with carbofururan bought in Tanzania; the most recent episodes were reported in January 2011 (further discussed in Section 3.4.3).

3.4.3 Methods used to assess repercussions to scavenging mammals

Records of predator poisoning in the African bush are inevitably incomplete. These events occur in the remote areas where predators still occur, and as they are illegal, the perpetrators keep them secret. Few carcasses are found by conservation authorities or NGOs, there is no formal reporting or central record keeping system, and communication between conservation groups is often minimal. Given the rapid rate of decomposition in the tropics, it is rare for trained personnel to find carcasses before they are decomposed and eaten by scavengers, and freezers for storing tissue or gut content samples are not often available in the field. Kenya's Pest Control Products Board (PCPB) has appeared reluctant to accept evidence of predator poisoning, and since use of Furadan to poison lions became controversial following the US publicity, the one laboratory in Kenya capable of analysing for carbofuran metabolites refuses to accept wildlife material.

The reports compiled by the predator conservation group Living with Lions (LWL) come from a variety of sources in Laikipia and Kajiado Districts. Some were direct observation of radio collared lions that LWL field personnel have discovered after receiving a mortality signal, some were reported by local people and investigated by LWL, others were reports received from individuals or conservation groups that we consider reliable.

3.4.4 Results

LWL has records of 53 lions poisoned in our 7 000 km^2 Laikipia study area since 2002, and 68 in the 5 000 km^2 Amboseli region since 2001. All Laikipia incidents occurred on communal land, but as few lions survive in these areas, most probably originated on commercial ranches. All Kajiado incidents were on communally owned group ranches. The largest single recorded incident killed a pride of seven adults and subadults. Additionally, the Kenya Wildlife Service has many poisoning records from the Masai Mara region. In most other parts of Kenya, dead carnivores are unlikely to be reported due to lack of conservation activity, so these records represent an unknown fraction of the actual number of lions poisoned in Kenya.

Hyenas have also suffered heavy poisoning mortality and have become rare in most areas. However, they are less likely to be found than lions as they tend to move away from an unfinished carcass, and low public interest in hyenas means that dead ones are not usually reported unless they are found in conjunction with dead lions. In a typical example, five dead hyenas and two dead vultures were found by a LWL scout in the Amboseli region in November 2010, next to a cow carcass sprinkled with blue granules. Although wild prey was abundant in this region until the drought of 2009 (African Conservation Centre 2010; KWS and TAWIRI 2010) and livestock carcasses and human refuse are ubiquitous, hyenas have become notably uncommon in this region (LWL, unpublished data), the apparent result of years of intensive poisoning.

The most recent incidents were reported by scouts from the African Wildlife Foundation and followed up by a scout from the Masailand Preservation Trust and one from LWL's Lion Guardians group (i.e., Masai warriors employed in lion monitoring and conservation, see www.livingwithlions.org). On 2 January 2011, just on the Tanzania side of the Tanzania-Kenya border, a livestock owner freely admitted to sprinkling carbofuran on the carcass of a cow killed by lions. A female lion, four spotted hyenas and a vulture were poisoned. On 19 January, the same man poisoned another cow carcass, which was fed upon by one male and three female lions; the male died (Figure 3.14) and after being partially skinned (skins, teeth and claws are illegally sold to tourists) and more blue granules were sprinkled on the lion, apparently in an effort to kill additional hyenas (Figure 3.15). The lions are thought to have originated in Amboseli National Park, on the Kenya side of the border.

In a similar incident in April 2010, a pride of five lions from Amboseli National Park was poisoned in Kenya, along with one striped hyena (*Hyaena hyaena*). The perpetrator admitted to buying Furadan in Tanzania, and the Kenya Government Chemist's analysis of lions' stomach contents reported carbofuran in all samples. Thus, although Furadan is now more difficult to buy in Kenya, carbofuran remains freely available in Tanzania and can be easily brought into Kenya. In Tanzania, it has also been documented as being used to poison crocodiles and vultures in the Selous Game Reserve (R. Bonham, personal communication). Furadan is also apparently still widely available in Uganda (E. Okot Omoya, personal communication). At least 11 lions were poisoned with Furadan in Uganda's Queen Elizabeth National Park in 2007, (http://www.newvision.co.ug/D/8/12/577946), and populations of all large predators plummeted after pastoralists invaded the Park in 2006. '"Over 80% of the hyenas have been killed and all leopards along the Nyamusagani River have been poisoned," said Dr. Ludwig Siefert, a veterinarian and lecturer at Makerere University.' In typical cases, however, the dead lions, hyenas, or vultures are only found and reported days after death, and due to decomposition and scavenging, little evidence is left. It is rare for someone to arrive on the scene

Figure 3.14 Male lion poisoned over the Tanzanian border (January 19, 2011)
Photo taken by Patrick Ole Saiyalel

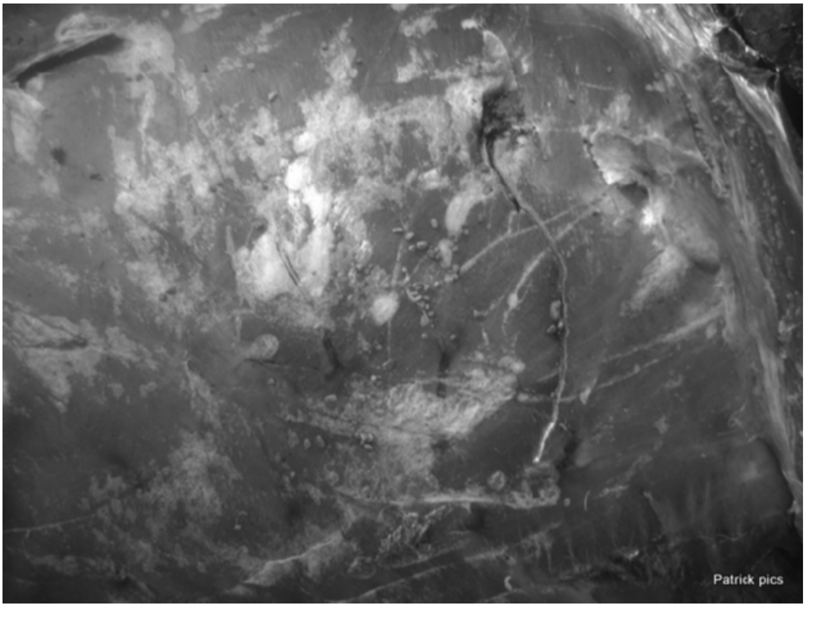

Figure 3.15 Granules (suspected to be Furadan) on poisoned lion, Tanzania (January 19, 2011)
Photo taken by Patrick Ole Saiyalel

while the carcasses are still fresh, and evidence in the form of granules or piles of dead flies on the bait are still visible. Because scouts and rangers are not trained in toxicology, stomach content and tissue samples are rarely taken.

Although few samples have been analysed, the people doing the poisoning readily describe using Furadan, and agrovets are familiar with this use for it. As strychnine and highly toxic acaricides are no longer available, there is no other readily accessible poison. Although definitive and reliable laboratory analyses are available for relatively few carnivore poisoning cases from Kenya, there is overwhelming anecdotal evidence that carbofuran has been used, and continues to be used, to eliminate predators in Kenya and elsewhere in Africa.

3.4.5 Discussion

Extinction of wildlife is ultimately due to failure of conservation policy and action. Loss of Kenya's wildlife is especially tragic in view of the fact that wildlife tourism has long been one of the most important pillars of the national economy. Lions are the single most important species that attract foreign visitors with their dollars, euros and yen, and their elimination would almost certainly have a major negative impact on tourism.

Although conservation resources are inevitably limited in developing countries, much of the responsibility for the decline in wildlife lies in national policy that denies significant income from wildlife tourism to the rural people who bear the costs of living with wildlife (Norton-Griffiths 2007). Disease and drought are much more important causes of livestock loss (Frank 1996), but predators are seen as an immediate threat that herders can control (Hazzah, Borgerhoff Mulder and Frank 2009). As long as lions and other wildlife are no more than an expensive nuisance, it is hardly surprising that people eat what is edible and poison the rest. Without a reversal in policy that makes wildlife a valuable economic resource for Africa's pastoralists, it will continue to decline. Until African governments take wildlife resources far more seriously, there is little chance of an improvement in the outlook for wild animals and their habitats. In the meantime the only feasible way to prevent abuse of pesticides for poisoning wildlife is for governments to ban importation and manufacture of highly toxic compounds such as carbofuran. Since the pesticide industry claims that there is little legal evidence that carbofuran is used to poison wildlife (i.e., the 'innocent until proven guilty' defense), we need a concerted effort to analyse samples recovered from carcasses to confirm the identity of the compound(s) used to poison wildlife.

3.5 Threats of secondary Furadan poisoning to scavengers, especially vultures, in Kenya

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3.5.1 Misuse of Furadan to control farm pests

In Africa, owls are culturally taboo. People believe, for example, that the sight or sound of an owl brings bad luck in the form of death or illness in one's family. Ogada and Kibuthu (2008) provided an account of the knowledge and perceptions of farmers regarding eagle owls in Central Kenya. Given

such negative beliefs about owls, as part of their research, these authors asked farmers about their use of pesticides (since they could pose an obvious threat to owls feeding on farm pests, particularly rodents). Although they reported that agricultural pests posed the most serious threat to their livelihoods, only 28% of farmers stated that they used pesticides to control vertebrate pests such as rodents and mousebirds (Collidae), which feed on their crops. Of these, 45% admitted using Furadan to poison rodents and to a lesser extent, mousebirds.

The (mainly poor) farmers interviewed stated that they used Furadan, due to its high toxicity (and hence its effectiveness), its affordability and its widespread availability. Field observations confirmed largely unsuccessful attempts at poisoning rodents and mousebirds by slicing open a ripe tomato still attached to the plant and smearing a layer of Furadan on its surface (a practice also carried out in Croatia, see Chapter 5) in anticipation that the pests would feed on it and die. The authors received anecdotal reports from field workers that a number of mousebirds poisoned by ingesting Furadan were later consumed, presumably while in an incapacitated state, by a Mackinder's eagle owl (*Bubo capensis mackinderi*) that itself died.

3.5.2 Effects of Furadan on vulture populations in Kenya

Of all the wildlife species in Kenya, vultures have suffered disproportionate declines due to Furadan poisoning, more than any other non-target species. Although lions have likely been hardest hit in terms of their overall population declines, vultures are hands down the largest unintentional victims of poisoning due to their reliance on carrion for almost their entire diet (Mundy, Butchart, Ledger et al. 1992). In addition, vultures are extremely vulnerable to poisoning because they forage communally, often in very large numbers, which means hundreds can be killed at a single poisoned carcass. Reports of mass vulture deaths in Africa due to poisoning are numerous (e.g., Borello 1985; Allen 1989; Anderson 1984; Simmons 1995). In April 2004, S. Thomsett witnessed the after effects that one carcass baited with Furadan can have on the scavenger community. In this incident, 187 vultures of three species perished alongside a number of spotted hyenas (*Crocuta crocuta*) in the Athi River. Vulture samples collected and analysed by the Government Chemist tested positive for residues of carbofuran (Government chemist, unnamed, personal communication, 2004).

Since 2007, conservationists in Kenya have recorded the deaths of 366 vultures due to poisoning (J. Clark, unpublished data) and this number is likely an underestimate of the actual total. Not included in this amount are other well-known scavenging birds including bateleurs (*Terathopius ecaudatus*), tawny eagles (*Aquila rapax*), Steppe eagles (*Aquila nipalensis*), fan-tailed ravens (*Corvus rhipidurus*), and Marabou storks (*Leptoptilos crumeniferus*), many of which have perished from consuming baited carcasses (J. Clark, unpublished data). Though the majority of poisoning cases (as supported by laboratory tests or strong anecdotal evidence) are linked to Furadan, other pesticides have also been used to poison wildlife, including amitraz (an antiparasitic agent/acaricide), cyhalothrin (a pyrethroid insecticide) and Marshal (carbosulfan, another carbamate whose chemistry is briefly detailed in Chapter 1).

Because they travel long distances to find carcasses and reproduce slowly, vulture populations can be extremely hard hit by wide-scale poisoning and their populations are slow to recover, if at all. A decade ago, none of the vultures found in Kenya were listed on the IUCN Red List of Threatened Species. At present, five out of eight species are Red-listed and populations continue to decline (Ogada, Torchin, Ezenra et al., in review). In fact, no other functional group of birds has faced such a heightened threat of extinction within the last decade.

Two recent studies confirm that Kenya's vultures are declining rapidly. Virani and colleagues (2010) documented large declines of vultures and other scavenging birds in and around the Masai Mara National Reserve over the last 30 years. Staggering declines in abundance were recorded for seven of eight scavenging species. Significant declines were recorded for Egyptian (−100%),

hooded (−62 %), *Gyps* (−52 %), lappet-faced (−50%), and white-headed (−44%) vultures. The authors attribute the declines to land-use changes outside the reserve, but further note that due to declines seen inside the reserve, human activity, specifically poisoning, is suspected to be an important cause of the declines. The wider Mara region has been the site of a growing number of poisoning incidents and many vultures and other scavengers have been killed particularly in recent years (Mijele 2009; Martins and Kahumbu 2009; Noonkipa, unpublished report).

Ogada and Keesing (2010) showed that over a three-year period raptors declined more than 40% per year from 2001 to 2003 in Laikipia District (central Kenya). Overall, raptors declined by 70% during the surveys and scavenging birds, particularly vultures, accounted for most of the decline (Ogada and Keesing 2010). During the same period, overall populations of large wild herbivores showed little change and domestic herbivores (particularly sheep and goats) increased, implying that food limitation was not responsible for the observed declines. The authors suspected that the rapid decline of vultures was due to consumption of poisoned baits laced with Furadan which pastoralists were increasingly using to kill large predators that attacked their livestock (Odino and Ogada 2008b). A report by Otieno and colleagues (2010b), discussed further in Section 3.6, which follows, confirmed the death of an African white-backed vulture (*Gyps africanus*) in Laikipia District as a result of Furadan poisoning. Throughout Africa, hooded vultures (*Necrosyrtes monachus*) have shown large declines (45 to 78%) over the past four to five decades. In East Africa, declines averaged 63%, with poisoning being a significant factor suspected in their declines (Ogada and Buij 2011).

Vultures provide one of the most important yet underappreciated ecosystem services of any avian group (Sekercioglu 2006). As the only known obligate scavengers, they provide essential ecosystem services, foremost of which is the disposal of rotting carcasses. In a sense, they are the catalysts of carcass disposal. They can fly quickly over large distances to locate and decompose carcasses efficiently and mammalian scavengers often follow them to carcasses. For this same reason vultures may also be targeted by poachers because their presence or proximity can give away the location of their camps (S. Thomsett, personal communication, 2010). Scavengers such as the Marabou stork cannot easily feed on a carcass unless/until vultures have opened it, picked at it and made it more accessible.

The potential consequences of vulture declines include changes in scavenger community composition and increased rates of disease transmission at carcasses. A recent study by Ogada, Torchin, Ezenra et al. (in preparation) has shown that without vultures, carcasses decompose more slowly (approximately 27 hours as opposed to 12) and greater numbers of mammalian scavengers spend more time in close proximity to carcasses. One consequence was a 50-fold increase in the number of contacts between mammalian scavengers, mainly hyenas and jackals. Such contacts between individuals were used as a proxy for disease transmission at carcasses as close contact between individuals is a likely source of pathogen transmission for a number of carnivore diseases including rabies and canine distemper, for which hyenas and especially jackals are well-known hosts (Loehle 1995; Murray, Kapke, Evermann et al. 1999). Based on the findings, the authors (i.e., Ogada, Torchin, Ezenra et al.) expect an increase in the spread of carnivore diseases at carcasses as vultures decline or become locally extinct.

Vulture populations in Kenya are under serious threat particularly due to Furadan and carbamate poisoning. Although the evidence presented here is largely with respect to vulture studies conducted in Kenya, further evidence links other countries in the East African region (in particular Tanzania, Uganda and Ethiopia) to vulture declines as a result of Furadan and carbamate poisoning. If the current situation with regards to vulture poisoning continues, it is not unreasonable to expect extinctions of most vulture species in Kenya within the coming decades with concurrent ecological consequences for the scavenger community and increased rates of disease transmission at carcasses.

3.6 Forensic analysis of carbofuran in vultures and environmental samples collected from Laikipia and Isiolo Districts

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From the 1990s onwards, an increasing number of lion and vulture poisonings, purportedly with Furadan, have been reported in Laikipia and Isiolo District. Granular Furadan was known to be widely used in agricultural areas around Lewa and Ol Ar Nyiro wildlife conservancies in Isiolo and Laikipia Districts, respectively, to control agricultural pests (Otieno, Lalaha and Virani 2010a,b). In response, Dr Munir Virani, an ornithologist with The Peregrine Fund and National Museums of Kenya, initiated an investigation in August 2007 to more rigorously evaluate Furadan involvement in the high vulture mortality cases that were reported and to carry out an assessment of carbofuran use and exposure in the districts of Laikipia and Isiolo. The project was funded by The Peregrine Fund, through the Africa project, and the research was conducted by Peter Otieno as part of post-graduate studies in environmental chemistry at Maseno University, Kenya. This section summarises the study and its results. For further details, including sampling method and analytical parameters, the reader is referred to Otieno (2009 thesis) and to Otieno, Lalah and Virani (2010a,b).

First, the a) amount of Furadan applied locally for agricultural purposes, b) formulations and application methods used, c) application rates, d) potential non-target organisms exposed, and e) characteristics of catchments on farms and potential environmental contamination of soil and water bodies such as rivers, canals and ponds within the two districts were all carefully documented. Samples of soil, water, plants and vultures (talons and beaks) were collected and analysed for residues of carbofuran and metabolites, to evaluate levels in the environment/wildlife and identify potential routes of exposure. The Ngare-Ndare and Ngare-Sirgoi rivers in Isiolo, the Kinamba dam and a dam inside the Gallman Memorial Wildlife Conservancy were chosen for this study. Apart from being adjacent to the conservancies, they are located within the catchments of agricultural sectors likely to contribute to residue contamination. Prior to this, few studies had evaluated secondary poisoning (non-point sources) such as exposure to carbofuran-contaminated water in Kenya (Lalah and Wandiga 1996a, b).

Vultures were selected for this study because initial reports indicated they were dying in large numbers at baited carcasses in the study area. Vultures are at the top of the scavenger food chain, are communal feeders and are extremely vulnerable to eradication from poisoning (as previously discussed in Section 3.5). Their absence constitutes a clear indication that the environment has been compromised. The threat to species such as *Gyps africanus* and *Gyps ruppellii,* which are obligate scavengers, is further exacerbated by the fact that they are a long-lived species and have a very low reproductive rate (i.e., they lay one egg at a time) so their populations are sensitive to even small declines in the number of breeding adults (Slotta-Bachmayr, Bogel and Camiña 2004). Under natural circumstances, vultures have high adult survival rates, which can compensate for low annual offspring production. However, incidents of mass mortality such as the death of over 20 vultures

following one poisoning event (May 2007 in Lewa) presents a significant negative impact on the demographic viability of this species.

3.6.1 Survey result

Furadan appears to have been primarily used in the two districts as a pesticide to control soil dwelling and foliar feeding pests in maize cultivation and on horticultural farms. The survey showed that over 70% of the large-scale farmers who use Furadan are situated in Laikipia District. The survey also confirmed that all incidents of wildlife poisoning by farmers and pastoralists in the two districts were carried out to avenge the killings of their livestock by lions. This practice, and lion mortality in Kenya, was discussed in Section 3.4.

Although alternative compounds such as methomyl (90% w/w), Mocap GR10, Nemur 400EG and bio-pesticides like nimbecidine and bio-nematon were available on the market, farmers seem to favour carbofuran (i.e., Furadan) to control pests. Stockists in both districts sold Furadan (in sizes ranging from 100 g packs to 200 g plastic canisters), with labels in English and Kiswahili, especially during the planting season. The stockists we interviewed said they were not aware that Furadan could be used to poison wildlife.

3.6.2 Analysis of environmental sample

The results of the environmental sample analyses demonstrated that carbofuran was used extensively in the two areas (especially in Laikipia). Elevated concentrations of carbofuran and its two major metabolites (i.e., 3-hydroxycarbofuran and 3-ketocarbofuran) were detected in the soil, plant and water samples collected with recoveries in excess of 75%. Analysis of carbofuran metabolites is very critical to forensic investigations, because they appear to persist longer and can occur in higher concentrations than the parent compound. This is significant in tropical conditions where carbofuran dissipation from the site of application can be quite rapid (as previously discussed in Section 3.2).

3.6.2.1 Water residue results

The mean concentrations of carbofuran detected in both Isiolo and Laikipia (i.e., between 0.5 and 495 μg/L in two rivers and below detection level to 2 301 μg/L in ponds and dams close to farms) were above both the European Union limit (i.e.,1 μg/L) and the US allowable contaminant level (i.e., 40 μg/L) (Pogacnik and Franko 1999). These levels were also above the maximum concentration limit (MCL) recommended by WHO for drinking water. As such, these residue levels pose risks when the contaminated water is used for domestic purposes or as drinking water for agricultural animals. The solubility of carbofuran in water and its rapid degradability likely account for the observed decrease in concentration downstream as well as the presence of the two metabolites. Generally, the results showed a marked increase in the concentration of metabolites from the wet to dry season. There was also a significant difference ($p < 0.05$) in mean concentrations of carbofuran and its metabolites in the wet and dry (sampling) seasons in both districts, though the concentration of carbofuran and its two metabolites was higher in water sampled from Laikipia.

3.6.2.2 Plant residue results

As a systemic compound, carbofuran is absorbed through the roots and then distributed throughout various plant organs, mainly the vessels, stems and leaves. As such, it can be detected in the leaves seven to ten days after application (Crocker 2005). Carbofuran and its two metabolites were detected

in plant samples collected from both Isiolo and Laikipia Districts. A higher concentration of carbofuran was observed in the first sampling (October) than in the second (June) because most crops were still green (i.e., the photosynthetic process was at its apex) in October, resulting in a higher insecticidal concentration in the leaves. The difference in mean concentrations of carbofuran and its metabolites in plants collected during the dry and wet seasons in both regions was also significant ($p < 0.05$), with higher concentrations observed during the wet seasons.

3.6.2.3 Soil residue results

Carbofuran residues were detected in soil and, as was the case with the plant samples, the concentration was higher during the wet season. This is because the compound readily dissolves and percolates towards the soil matrix shortly after application. In-furrow application is meant to reduce cases of exposure and poisoning, however, this practice has repeatedly given rise to extensive bird mortality in organisms that sift through soil (see Chapters 7 and 8). However, we did not encounter any such cases of field poisoning during sampling and no additional investigation was done. Mean concentrations of carbofuran, 3-ketocarbofuran and 3-hydroxycarbofuran varied both regionally and seasonally ($p < 0.05$) in soil sampled.

Carbofuran metabolites were also found at low concentrations in the soil samples taken from the site at Lewa Wildlife Conservancy where two lions were poisoned and over 20 vultures were found dead. Similar soil contamination, from laced carcasses, has been reported by Vyas, Spann, Albers et al. (2003). Pesticide residues can be transferred to the surface of the soil from a laced carcass, either during lacing or from seepage. Since the survey established that no other forms of carbofuran (i.e., liquid formulations) were available in the two districts, the carcass was most likely baited with granular carbofuran. Concentrations of the compound and its metabolites in soil from other sampling sites were significantly elevated and indicated usage of carbofuran in the two districts.

3.6.2.4 Analysis of vulture samples

In addition to some of the more mundane sampling difficulties (described by Crocker 2005), the author found it challenging to locate fresh carcasses of birds that had died from poisoning due to factors that included the vast extent of the land around the conservancies, the overall hostility and suspicion of the pastoral community and having to remain vigilant against attack by bandits and cattle rustlers. Given the inherent difficulty in finding fresh avian tissues, feet (i.e., talons) and beaks were collected for analysis instead, following the method of Vyas, James, Craig et al. (2005). Although the length of time that the samples (see Figures 3.16 and 3.17) were in the field after exposure could not be ascertained, residues of carbofuran were nonetheless detected in the beaks and feet, providing positive confirmation that the vultures were exposed to this pesticide before they died.

Vultures that ingest carbofuran-poisoned tissues very rapidly become (acutely) intoxicated/comatose and are frequently recovered dead, right beside a poisoned carcass (Brown 1997). While the residue levels detected in the feet and beaks do not necessarily imply exposure to a lethal dermal or oral dosage, they do provide evidence that the bird in question was exposed to carbofuran (Stroud and Adrian 1996). According to Martin and Forsyth (1998), despite the tougher, scalier skin of bird feet/talons, they are by no means impermeable to pesticides, which implies that the birds may have absorbed a higher amount of the compound than indicated by the residue levels detected in the feet, which should be viewed as a lower level of exposure. Vultures and other scavenging birds step on a carcass as they feed, providing plenty of opportunities for a pesticide/contaminant to be absorbed dermally or through the foot pads. This explains the presence of carbofuran and its metabolites on the birds' feet, even if in low concentrations.

Figure 3.16 Vulture carcass recovered from the field during the Laikipia/Isiolo study
Photo taken by Peter Otieno

Figure 3.17 Beaks and feet of poisoned vultures, which were analysed for the presence of carbofuran and its metabolites
Photo taken by Peter Otieno

Muscle samples from carcasses collected from the Athi River were also analysed because several vultures had been found lying dead beside them and, though carbofuran was not detected, residues of 3-ketocarbofuran and 3-hydroxycarbofuran were. Hence, intentional poisoning of predators, and therefore secondary poisoning, was the main cause of the mass mortality of vultures, as confirmed by the presence of carbofuran and its metabolites in carcass meat and in vulture feet, beaks and crop content.

3.6.3 Conclusions of the study

The results of the survey combined with the concentrations of carbofuran and its metabolites (3-keto-carbofuran and 3-hydroxycarbofuran) detected in water, plant, soil and vulture samples suggests that carbofuran/Furadan was used extensively in the two study areas (especially in Laikipia). The environmental distribution and presence of residues in local water sources, which may pose risks when used for domestic or agricultural purposes (i.e., in drinking water for animals) was particularly disconcerting. The concentrations in environmental matrices (e.g., water) were elevated and, in our view, provide sufficient evidence to support the concern that carbofuran menaces vultures in the two districts and the current campaign to generate awareness about Furadan use in Kenya. The next section details the poisoning of what are, in our view, highly underappreciated organisms, namely non-target, beneficial insects.

3.7 Repercussions of pesticides (including carbofuran) on nontarget, beneficial insects and use of insects in forensic analyses in Kenya

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3.7.1 Studies on nontarget insects

Many of the insect species that are not targeted by pesticide applications provide economically important services, such as pollination and natural pest control. Ecologically speaking, nontarget insects also represent a significant food source for birds, particularly during the nesting season (Moreby, Sotherton and Jepson 1997). In the last 20 years or so, a growing number of studies have examined the risks that pesticide applications pose to nontarget, beneficial arthropods, particularly species termed ‘natural enemies’, and pollinators, primarily bees (Desreux, Decourtye and Delphwech 2007). In this regard, a comprehensive series of global case studies on natural enemies and biological control can be found in Cock, van Lenteren, Brodeur et al. (2009).

In addition to direct mortality (the indicator most frequently used to measure pesticide exposure risk) Desreux, Decourtye and Delphwech (2007) recommended examining sublethal effects on arthropod physiology and behaviour, for which there are currently no standardised methods of assessment. Other important factors that can be impacted include: developmental rate, immunology, fecundity, sex ratio, mobility and navigation, feeding behaviour and detection of food resources (Desreux, Decourtye and Delphwech 2007).

Pesticide management recommendations (including those from FMC, the manufacturer of Furadan) have included reducing or mitigating drift into areas on the outer periphery of agricultural zones, which often host a high insect diversity (Moreby, Sotherton and Jepson 1997). Reducing or restricting the use of certain pesticides known to be harmful (e.g., fenitrothion) is also suggested (Brittain, Vighi and Bommarco et al. (2010) in Dicks, Showler and Sutherland 2010). Work on the links between pollinator diversity and crop production (i.e., Martins and Johnson 2009) have demonstrated the link between maintaining biodiversity and agricultural productivity to bridge the gap between agricultural development and conservation. In addition to protecting beneficial insects from exposure to potentially lethal pesticides, such actions will also help ensure the availability of critical habitat components such as larval host plants, places to oviposit and wild sources of nectar.

Very few studies have examined pollination by wild insects in the tropics, though their presence greatly benefits crops there (Martins and Johnson 2009). The author’s own work on the potential

effects of pesticides has included two areas, namely honeybees/pollinators and dragonflies as indicators of aquatic habitat quality. Wild insects other than bees (e.g., hawkmoths (*Macroglossum stellatarum*)), are now increasingly recognised as valuable pollinators and there is a movement afoot to maintain healthy populations of a variety of pollinator species in Kenya and elsewhere (Martins and Johnson 2009). In addition, there is growing evidence of an overlap in wild pollinators between crops and endangered wild flora. Therefore, the decimation/poisoning of pollinators visiting crops has cascade effects on plants in wild areas through loss of the specialised pollinators (Martins 2008).

Insect exposure to pesticides is not solely confined to agricultural regions and practices in Kenya. The author recently investigated the harmful effects of 'pesticide fishing' on invertebrates in Lake Victoria, focusing on Odonata, an order which includes dragonflies and is a very useful indicator of water quality (Martins 2009). Pesticide fishing is a practice whereby a pesticide is sprayed or granules are sprinkled onto the surface of a body of water and the fish that float to the surface are collected either for personal consumption or sale in the markets. Indeed, we have seen pesticides displayed for sale in shops that carry fishing gear and tackle and have strong anecdotal/observational evidence that Furadan has been used for this purpose (Martins 2009). As the world's second largest freshwater lake, Lake Victoria provides important habitat for avian species and aquatic organisms. During this study, the author noted evident differences in the number of dragonfly species observed in areas that were pesticide-fished and those not subjected to direct application of pesticides (i.e., 1 to 2 as opposed to > 20, respectively). The use of pesticides to capture fish for human consumption appears to be an increasing trend in East Africa (Martins 2009).

Studies that establish the role of selected insects in pollination and natural defence and that identify species of special interest/significance are needed to further our understanding of the situation, both in Kenya and elsewhere. Work should also be undertaken to assess the repercussions of carbofuran and other compounds to pollinator and natural defence species and determine which of the compounds presently in use are of particular concern. The results of these studies would also be highly relevant to work being undertaken on threats to insectivorous birds and mammals. Residues of a number of compounds have been detected in fish in Kenya (refer to Section 3.2. and see Table 3.6), and carbofuran levels, including metabolites, in fish intended for human consumption, both pre- and post-capture, should be investigated.

3.7.2 Overview of insect diversity and abundance at a mammalian carcass: the use of insects in upcoming forensic investigations in Kenya

Insects are everywhere, and they have been called 'the little things that run the world' (Wilson 1987). Insects can offer a significant amount of information about carcasses, as evidenced by the extensive use of forensic entomology in current general forensic practice (e.g., Fernández 2010). Insects are often the first of the scavengers and decomposers to arrive at a carcass. Proper observations of insects and their behaviour (particularly abnormal behaviour and mortality in and around a carcass) and toxicological analysis of insects recovered from the carcass and immediate vicinity can help identify or narrow the compound(s) used. The presence of various species can also be used to estimate time since death.

As part of our efforts to increase the uniformity and robustness of field sampling procedures following wildlife mortality in Kenya, the author recently developed a generalised timeline of insect activity at a 'typical' mammal carcass (see Figure 3.18), assuming that cause of death is unrelated to poisoning. Most of the insect diversity associated with carcasses in East Africa is poorly studied and remains to be described. As far as we know, this timeline is the first of its kind in Kenya, and as such it is still a working outline, intended as a general guideline to be further refined.

Flies are among the first insects to arrive at a carcass, especially *Lucilia* species. These species land within a few minutes to a few hours after death. Many different kinds of flies will visit a carcass

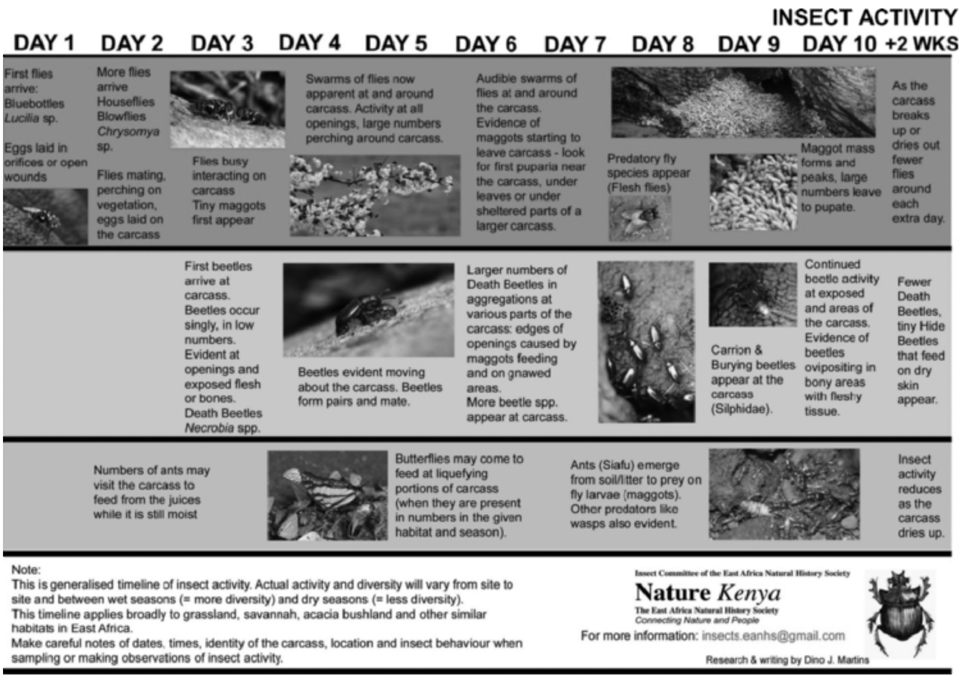

Figure 3.18 Generalised timeline of insect activity and diversity at mammalian carcasses in Kenya

and use it as a breeding site. They lay eggs that hatch into fly larvae (i.e., maggots), which are among the most important decomposers of a carcass. On large carcasses, such as elephants, the maggots soon form a writhing mass and facilitate the rapid digestion and breakdown of the carcass. They are also preyed on by birds, mammals like civets and shrews, as well as many other insects such as carnivorous beetles, wasps and even other maggots, which means there is potential for secondary exposure to any compounds on the carcass.

Maggots form a large mass that peaks in size at approximately one week to 10 days after the animal has died. Then a large exodus of maggots occurs as they seek out sheltered areas in surrounding litter or soil to pupate. At large carcasses, maggots often pupate under the carcass itself. If you gently dig in the soil or leaf litter you will often find pupae that are smooth, dark brown oval/oblong in shape. These can be collected and kept in containers till they hatch out to see what flies were using the carcass. Often maggots will pack themselves together lengthwise so only the tips of their bodies are visible. They facilitate one another by feeding 'en masse' and secreting digestive juices. Their activity also raises the temperature of the carcass significantly (by up to 10 ºC higher than the surrounding ambient environmental temperature).

Soon, other species of flies arrive at the carcass, including copper-tailed blowflies (Calliphoridae), houseflies (Muscidae), and eventually flesh flies (Sarcophagidae). These species are soon followed by beetles. The common carcass-visiting beetles in Kenya are death beetles (*Necrobia*), which also breed on the carcass. Other beetle species (e.g., carrion beetles), arrive and feed in low numbers. The maggots and death beetles are obligate carcass feeders (i.e., they require carrion for their life-cycle and development). Many opportunistic species also visit carcasses, including numerous predators such as wasps and ants.

Of course, the diversity and timeline observed will vary from site to site, across seasons and according to the species of the deceased animal as well as the density and behaviour of other scavengers. This timeline can be fine tuned as our stakeholders and researchers on the ground collect data on insects over time and in these distinct conditions. In addition, we are unsure of how this timeline may be impacted if the carcass being fed on is contaminated with a pesticide such as carbofuran. Given that the insects which feed at contaminated carcasses can themselves become exposed and secondarily poison the organisms that feed upon them, the author has also developed an outline for sampling/observing insects at carcasses for toxicological analyses (Martins 2010, available upon request).

3.8 Analytical, legal and regulatory mechanisms in Kenya

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3.8.1 Analytical methodology required and research capacity available in Kenya

The range and types of analyses, analytical instruments and techniques that are used to detect carbofuran and its metabolites as well as their relative costs and the analytical background required to conduct analyses and interpret results are described in Chapter 1. Unfortunately, the existing analytical capacity in Kenya is currently no match for the frequent pesticide-related incidents of mass mortality reviewed in this chapter. The presence/absence of carbofuran within a sample recovered from the field tends to be established using TLC. Other bioassay techniques (e.g., the ELISA method and cholinesterase assays, described briefly in Chapters 1 and 2, respectively) have not really been explored in Kenya. And, while bioassay techniques are more rapid and require less training/analytical background to conduct and interpret, they are also considerably less specific.

When circumstances permit, samples are analysed using ‘high precision’ instruments such as HPLC and GC/MS. HPLC systems are available in a few universities (e.g., Maseno University), where they have been used to quantitatively analyse carbofuran in various matrices including water, plants, soil and animal tissue after careful solvent extraction procedures which usually consist of liquid-liquid, Soxhlet extraction or solid phase extraction (SPE), followed by column clean-up with Florisil or silica gel and concentration before injection into the instrument (e.g., Otieno et al. 2009). Within the entire country, we know of only a limited number of GC/MS instruments (i.e., up to ten) in a few universities. For example, there are two GC/MS at the Jomo Kenyatta University of Agriculture and Technology (JKUAT), both refurbished instruments donated by a UK-based charity. We are also aware of two at research institutions, one at KEPHIS and one at the International Centre of Insect Physiology and Ecology (ICIPE). To provide some perspective, Kenya covers an area that is about twice the size of the US State of Nevada (i.e., a little under 583 000 km^2). By contrast, we also know of individual institutions in developed nations (e.g., North America and the United Kingdom) which house approximately the same number of GC/MS instruments as there are in the whole of Kenya. The cost of sending samples outside of Kenya for analysis, even within Africa, is generally considered to be logistically and financially prohibitive.

Few of the available analytical instruments are fully operational due to the lack of financial resources and analytical expertise to ensure regular maintenance is carried out, capability to run them properly, and knowledge to interpret the results. Another important concern remains how to maintain the integrity of samples, which must be transported over distances from the field, under extreme environmental conditions, to the few analytical facilities that are in operation. There is little in the way of storage capacity (e.g., refrigeration or freezing units) in the bush and electricity tends to either be intermittent or severely restricted. Systematic and concerted protocols are still required to gather, store and transport samples from the field, and screen them both for carbofuran and for other potential compounds of concern. One of the recommendations of the Stop Wildlife Poisoning taskforce (see Section 3.1) was, in fact, the implementation of memoranda of understanding (MOU) with laboratories that could conduct the forensic tests, and adopting standardised procedures specifying the organs selected for analysis (e.g., liver, gastrointestinal tract, feathers and talons/feet), the amount and location of sample collected, and the storage and preservation procedures (e.g., freezing or refrigeration) post-collection.

A lack of credible, robust data is one of the most important and pressing impediments to conclusively (i.e., forensically) identify any compound(s) involved in incidents of wildlife poisoning. Without such evidence, it is virtually impossible to legally resolve or even convincingly address the issue. Fortunately, Kenya's conservation community has once again risen to meet this pressing challenge. However, it is very difficult to sustain the kind of effort and energy that is required, particularly since no person or conservation entity is currently coordinating these efforts.

3.8.2 Legislation and regulation of pesticides in Kenya

Many Acts, laws, policies and governmental bodies have been implemented to regulate pesticide use and address misuse within Kenya. The earliest recorded legislation regarding general usage and handling of pesticides in the country dates back to 6 September 1921 (when the Public Health Act Chapter (i.e., CAP) 242 was passed by the colonial government). Sixteen years later, a second Act of Parliament dealing with Cattle Cleansing (CAP) 358 was passed (on 27 April 1937). This Act prescribed various preparations for destroying ticks which are still retained in law, although several amendments have modified the original prescriptions. The Poisonous Substances Ordinance, based on the UK Act of 1952 to ensure the protection of employees against risk of poisons by certain substances used in agriculture and incidental and connected matters, was implemented in 1952.

The Pharmacy and Poisons Act of Parliament was passed in Westminster (UK) on 1 May 1957 and incorporated into law to regulate the pharmaceutical profession and the drugs and poisons trade. Included in this Act was the control of veterinary drugs and poisons with additional rules on selling and labelling poisons, including pesticides. The Food, Drug and Chemical Substances Act (Cap 254) was enacted by Kenyan Parliament on 11 May 1965. Under this Act, pesticides were given particular attention and the term 'chemical substances' was defined as: 'any substance or mixture of substances prepared, sold, or represented for use as a germicide, a disinfectant, an insecticide, a rodenticide, an antiseptic, a pesticide, a vermicide or a detergent'. The Act also set tolerance levels (in parts per million, ppm) in foodstuffs, i.e., matter intended for human consumption. To our knowledge, this law has never been effectively implemented, nor has it been reviewed or modified since being enacted.

The Factories Act (Cap 514) regarding workplace safety, and enacted to ensure safe factory working conditions, also covers pesticides. Other legislative laws passed by Parliament that have a bearing on pesticide use, distribution and control include the Agriculture Act (Cap 313), the Fertilizers and Animal Foodstuffs Act (Cap 345), the Forest Act Cap (385), the Plant Protection Act (Cap 324), and the Water Act (Cap 389). Presumably, all these statutes could be invoked in the event of a case involving pesticides, however, we are not aware of whether any of these have.

Except for the Poisonous Substances Ordinance of 1954, the rest of the aforementioned Acts remain in force. A replacement ordinance (Use of Poisonous Substances Ordinance), which regulates

the protection of people against the risks from exposure to poisonous substances, has been drafted but has still not been presented to Parliament. The most comprehensive pesticide regulation is the Pest Control Products Act, which became law on 19 May 1983. It was established to regulate the import, export, manufacture and distribution of products used to control pests and the organic function (i.e., the use and toxicity) of pesticides on plants and animals. Under this Act, a 'pest control product' was defined as a: 'device, product, organism, substance, or thing that is manufactured to directly or indirectly control, prevent, destroy, attract or repel any pest.'

One of the measures of the Pest Control Products Act was the establishment of the Pest Control Products Board (PCPB), an entity which became operational in October 1984. In addition to the PCPB, several other bodies are involved in regulating pesticides and advocating their safe use: the Kenya Environment Secretariat (KES), Crop Life Kenya (CLK), National Environment Management Authority (NEMA), Kenya Bureau of Standards (KEBS) and Kenya Safe Use Project (KSUP).

Created in the 1970s, KES is the coordinating body for all matters pertaining to the protection of the environment and provides a link to international organisations such as UNEP, FAO and WHO, through which important pesticide policy guidelines are formulated. Kenyan agricultural industries are required to implement the FAO code of conduct (http://www.croplife.org/public/code_of_conduct) on the distribution and use of pesticides.

Most distributors of agrochemical and related products/services throughout Kenya belong to Crop Life Kenya, whose objective is to ensure that members ascribe to the safety, packaging, labelling and use of these products (Wandiga, Lalah and Kaigwara 2002). CLK was initially established in 1958, as the Pesticide Chemicals Association of East Africa. At the time, members felt the need for a joint approach in establishing standards for local formulations, particularly dusting powders, following discussions with the Ministry of Agriculture. In 1977, the group's name was changed to Pesticide Chemicals Association of Kenya, when the first East African Community, which was started by the colonial administration and included Kenya, Uganda and Tanzania, was disbanded. Since then, membership has increased, and there has been one last name change (Agrochemicals Association of Kenya) before becoming Crop Life Kenya. For the record, Kenya, Uganda, Tanzania and other East African countries recently reunited in 2008 to form a new East African community.

The National Environment Management Authority (NEMA) became operational in 2001, with a mandate to cover all issues pertaining to environmental protection, including evaluating whether industries conform to waste disposal and toxic residue guidelines. As such, NEMA is directly concerned with the discharge and environmental fate of toxic pesticides. The Kenya Bureau of Standards (KEBS) is a statutory organisation whose mandate includes developing quality and standards guidelines and inspecting imports, including pesticides.

The Kenya Safe Use Project was initiated by the International Group of National Associations of Agrochemical Manufacturers (now the Global Crop Protection Federation (GCPF)), in 1991 (Rocco 1991). Through various taskforces, the Project objectives include a) improving standards in formulation plants and in pesticide registration procedures, b) providing training for those who transport pesticides, and retailers, stockists and end-users (i.e., farmers), c) establishing poisoning information and treatment centres, d) eliminating waste stocks of agrochemicals in an 'environmentally safe' manner, e) promoting the use of protective clothing when handling and/or using pesticides, f) improving the clarity and/or content of pesticide labelling, and, g) promoting the use of pictograms to educate school children on the hazards of pesticides and what precautions must be taken when using them.

By 2002, when the last report was made on the safe and effective handling of pesticides, the Project had trained approximately 500 000 farmers, stockists (which includes agrovets), distributors and health professionals in Kenya (Rocco 1991).

As a member of the United Nations, Kenya has in the past ratified most of the conventions which required a restriction (or total ban on) organochlorine compounds such as DDT, largely because the necessary mechanisms and policies existed within the government to do so. The current scenario regarding pesticide distribution, safe usage and regulation (particularly regarding acutely toxic

compounds such as carbofuran), is now more dynamic since there are several NGOs, including numerous wildlife conservancies, whose mandate covers issues such as human-wildlife conflict and protection of wildlife species from any threat (including poisons). While the involvement of these NGOs has led to general awareness in the general public about the existing pesticide laws and the need for their enforcement, many of the conservationists that work within them remain unconvinced that there has been a single case of these laws being enforced, even perhaps since their enactment.

The standard practice in Kenya has been for Parliament to pass sectoral laws, with the aim of protecting the environment. However, there is currently no umbrella law that encompasses all aspects of environmental protection, a subject of concern to various environmental NGOs and to UNEP since 1994 when the drafting of new environmental law began (KENGO/UNEP 1996). Such a bill has now been drawn under environmental law and the new constitution includes revised law on environmental matters, including pesticides. However, the current pesticide regulation has a major deficiency: it lacks cohesions and directionality of policies and statutes, which means it cannot be implemented effectively. Further, the penalties prescribed are simply not high enough to deter offenders from misuse of very toxic pesticides such as carbofuran. Kenya is therefore in real need of an environmental law that will tangibly protect its environment, people and wildlife. There should perhaps be optimism that pesticide regulation will become active within the current, new constitution of Kenya which was promulgated in 2010.

3.9 General conclusions regarding carbofuran use, misuse and monitoring in Kenya

Joseph Lalah and Peter Otieno[2]

This chapter has described how carbofuran (as Furadan) was first imported into Kenya in the 1960s for agricultural use, primarily in rice paddies (Section 3.3), and how it has subsequently been misused as a bait, to poison wildlife in retaliation for predation on crops and livestock and as a means of hunting/fishing for human consumption. In 2009, FMC announced a buy-back of Furadan in Kenya (though the use of the product within the country is not banned *per se*), after a segment featuring the use of the product to poison lions was aired on the US television programme '60 Minutes' (http://www.furadanfacts.com/InTheNews.aspx?itemId=1002). As of April 2011, Furadan is essentially absent from most agrovet shops in Kenya. However, in some cases it is still possible to purchase it 'under the table' at some shops, and it is apparently still feasible to obtain the product from adjacent countries (e.g., Uganda). Even those on the ground (e.g., researchers) find it difficult to firmly grasp and monitor the situation. We are frankly sceptical that Furadan will not resurface again once the international attention generated by the recent lion poisonings (see Section 3.4) has abated since FMC also pledged to withdraw Furadan from the Kenyan market in the 1990s (see Section 3.1) but did not do so until 2010, and only after the second alarm against Furadan was raised. Although there is evidently no shortage of governmental bodies or Acts in Kenya (see Section 3.8) what is really required, in our view, is firm action by the government, with the help and backing of the international community, to ensure that this product, and others like it, are rapidly and completely phased out of the market once and for all.

However, withdrawing Furadan or (any similarly toxic and popular products) is only a stop-gap solution at best. Until our perceptions towards wildlife change and the conditions that create human-wildlife conflict, particularly the decreasing wildlife habitat base, are addressed, wildlife poisonings will continue. The survey conducted in Laikipia and Isiolo Districts (see Section 3.6) revealed that human-wildlife conflict has partly arisen because of lack of strong Kenyan government policies to address it. The communities feel alienated from wildlife despite its big contribution to the country's economic development and view them as a nuisance and hindrance to their way of life.

The good conservation work undertaken by various wildlife conservancies and the KWS are contradicted by negative/derogatory public perceptions. It has been alleged that the conservancies and wildlife reserves have displaced communities for the benefit of wildlife species and populations. On numerous occasions, government authorities have also fallen short of compensating communities for the losses they have incurred, even as they themselves profited from tourist revenue generated by the presence of wildlife species. Most of the tourism revenue currently generated does not reach the surrounding communities, which in turn makes it more difficult for them to accept the value of wildlife, particularly when the presence of wild animals imposes on their livelihood or poses personal risks to themselves and their families.

Continued population growth, and the resulting increases in development and expansion within the various agricultural sectors is leading to an even greater use of agrochemicals to meet the required demands of production (see Table 3.1). The situation that has arisen with Furadan is symptomatic of a far more pervasive issue, namely that the Kenyan environment has, to all intents and purposes, been severely compromised by extensive input of chemical compounds and that the magnitude of such contamination remains largely undocumented. The studies that have been conducted intermittently have shown that often elevated residues of these agrochemicals are present in water sources used for domestic, livestock and irrigation purposes, in foodstuffs and animal products, and in human samples (e.g., breast milk) (see Table 3.6).

As such, considerably stronger efforts must also be directed towards investigating potential repercussions to human health, impact from environmental residues of Furadan after legalised agricultural application and from the practice of pesticide misuse in hunting/fishing (see Sections 3.3 and 3.7). While it is true that corporations (FMC, in this specific case) which have benefited financially from both legal and illegal uses of their product must acknowledge responsibility and act accordingly, the Kenyan government ultimately bears responsibility for maintaining the safety of its own people and of the biodiversity upon whose integrity a significant component of the economy rests. Based on the information consolidated within this chapter, we offer the following recommendations:

1. **Address the underlying pesticide/contaminant issues in Kenya**
   The residue data provided in Section 3.2 reflect the long-term, extensive input of pesticides into the Kenyan environment, and the relatively few documented impacts on its ecosystems and inhabitants. Until the issue of safe use and management of toxic compounds (including carbofuran) is resolved, and long-term monitoring initiatives are implemented, conservation efforts will be undermined.

2. **Establish an action network to respond to wildlife and human poisonings**
   There are still no clear guidelines on what procedures to follow in cases involving pesticide poisonings, whether animal or human. Such guidelines should address issues of information management, necessary actions to take (including first aid and administering antidotes/treatments) and legal action to deter future offences. This is an area that must be addressed as soon as possible.

3. **Strengthen and implement environmental laws and regulations**
   Enforcement of the existing laws has been ineffective and inadequate. Despite the astonishing number of Acts and regulations (see Section 3.8), and the frequent need to enforce them, only a handful of offenders have received derisory penalties in the last five years. Thus, the current legal framework must be strengthened and use made of the laws in place so that cases can be prosecuted accordingly. Pesticide regulations need to clearly identify the educational level and training that stockists should have.

4. **Improve analytical capacity and increase monitoring efforts**
   One of the major handicaps in mounting a case and taking action against the misuse of Furadan/carbofuran (and other such products) is inadequate local scientific evidence

(i.e., residue data) following alleged incidents of wildlife poisoning. It is also of paramount importance to identify any other relevant products/compounds that are being misused or whose chemical properties are similar to carbofuran (e.g., Marshal/carbosulfan). The forensic investigation detailed in Section 3.6 revealed residues of carbofuran and its metabolites in vulture tissue, talons/feet and beaks, and in soil, water and plant samples using HPLC and GC/MS. Further work of this type, also investigating residues of metabolites, should be pursued. The relevance of cholinesterase assays and field testing kits (as discussed in Chapter 1) in the Kenyan context and the feasibility of using such tests should also be explored.

5. **Pursue educational programmes on safe handling of pesticides and repercussions of misuse to people and wildlife**

   Section 3.3 discussed the use of workshops and informal meetings to outline alternative livelihoods, non-destructive means of managing wildlife conflict and the value of biodiversity to tourism. Negotiations with relevant parks and reserve authorities should also be undertaken to ensure that adjacent communities receive a just financial benefit from tourism. The national and international bird conservation authorities should consider upgrading the status of wildlife-rich irrigation schemes and other agricultural regions for conservation and tourism purposes, without hindering ongoing cultivation (e.g., construction of observatories and blinds for bird watching). In the case of wild bird poisoning for human consumption, if local communities can generate more revenue over a longer term, from having an abundance of bird species in their midst (and if poachers could be called upon to serve as birding guides instead), the short-term gains of poaching may be viewed in a different light.

6. **Better training and record keeping**

   The situation with Furadan has illustrated the difficulty in controlling the distribution of pesticides (and monitoring their misuse as baits) once they are on the Kenyan market. Proper usage and handling can only be achieved if the handlers are informed and if the products have clear, simple labels and instructions on the contents (including active ingredients) and the recommended dosages, in the relevant languages. Stockists, distributors and traders should be properly informed of the toxic limits, toxic effects, existing laws and regulations because they essentially have control of sales to the farmer. They could monitor and keep better records of pesticide product sales and deliver messages directly to agricultural and livestock farmers as well as other customers on safe handling, exposure and disposal of containers as well as penalties existing in the law for offenders. The PCPB could carry out spot checks and follow up in the market and in farms to verify the records of sale in agrovet shops and adherence to regulation.

7. **Better transparency and unrestricted access to information**

   As outlined in Section 3.8, the PCPB regulates the registration, importation, sale and distribution of pesticides and is mandated to maintain records of the amounts imported. The PCPB keeps a list of imported pesticides and their intended specific purposes, however access to this list is now restricted. One has to join as a member (annual membership fee of KSh 1000) before having access to information on their website. While this fee may be affordable to organisations, it can be quite a hindrance for individuals such as students or researchers who may need just a single access to the information. It also means the PCPB is not being open and democratic with important government information. Given that the list does not contain sensitive information, the reasons for restricting access are not entirely clear.

8. **Initiation of further studies**

   Agricultural areas should be more rigorously monitored for residues of agrochemicals. Ongoing monitoring efforts should assess the exposure risks and repercussions of aquatic species and beneficial insects, both currently under-represented in studies. It would also be prudent to conduct an analysis of foodstuffs poisoned using Furadan and destined for human

consumption (e.g., wild birds and fish) for residues of carbofuran and metabolites. In this same spirit, we are not aware of any studies having been conducted to assess repercussions to human health arising from occupational exposure (whether farmers or poachers), exposure to residues on/in foodstuffs or from consumption of contaminated meat obtained by pesticide-aided fishing/hunting. Kenyans (particularly those living in villages) tend to be quite reticent about providing urine or blood samples, so studies and research approaches will have to be designed accordingly. Such initiatives will require collaboration with medical experts and researchers.

9. **Establishment of rehabilitation capacity**
   Despite having some of the richest biodiversity in the world, the existing wildlife rehabilitation facilities in Kenya need further support. In the face of significant wildlife mortality, proper treatment facilities and release protocols are essential conservation tools. In this regard, the veterinary departments in universities and related institutions could be called upon to collaborate in helping to develop and maintain such facilities.

All these recommendations will require adequate funding and considerable support from the government of Kenya, and the international community, among others, if we are ever to tackle the underlying issues of human-wildlife conflict and the extensive environmental contamination within the country. Wildlife protection efforts should receive equal support to that offered for forest conservation. We can erect more secure and permanent perimeter fences to ensure the safety of wildlife and of the people and their farms. Government policies can also be implemented to deter human population and their activities from encroaching closer into the protected wildlife areas and the buffer areas. But we cannot manufacture the willingness and determination that must accompany such gestures. In this chapter, we are extending a plea to the international community and to the various organisations that draw up treaties regarding the safe use, monitoring and restriction of agro-chemicals, to help us address this issue now and not put it off any longer. Researchers and conservationists who have been at the forefront of this issue as it has unfolded are baffled by the muted response received so far, even after the poisoning of Africa's emblematic lions. As such, we wonder what sort of event would trigger a more definitive response. Would the poisoning of a highly cherished species such as a mountain gorilla catalyse the international community into immediate action? In the absence of any other plausible explanation, we are left to draw the inevitable conclusion that the international community and the government of Kenya have little regard for the health of Kenyans and are not fully engaged in ensuring the well-being of even our most highly charismatic wildlife species. Indeed it is ultimately the responsibility of the government and all the people of Kenya to ensure that we do not lose our precious wildlife; they are our children – unruly, special, each one irreplaceable, and should be protected at all costs. But we are struggling, and so, we ask for help to achieve this most monumental of tasks, before it is too late.

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Note

*In March 2011, a concern was raised that some of the Furadan in circulation on the market was in fact a counterfeit product. This allegation (based on a chemical analysis of one sample) is currently being investigated by stakeholders in Africa and in North America. FMC has also taken an active interest in the matter.

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4 Mitigating human-wildlife conflict and retaliatory poisonings in India to preserve biodiversity and maintain sustainable livelihoods

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4.1 Introduction

India is a densely populated nation which now has in excess of one billion inhabitants (1 160 813 000 projected for 2009), as per the Census of India (Report 2008b). This upwardly spiralling human population exerts an ever-increasing demand for food, water, fuel and infrastructure which must be provided from a fixed land base. Major extension to meet this demand is often into valuable wildlife habitat, which is deeply unfortunate because India has a rich repository of wildlife and a remarkable biological diversity of flora and fauna. This country supports an estimated 4 to 5% of all the world's plant and animal species, including 2 546 species of fish, 210 species of amphibians, 496 species of reptiles, 1 228 species of birds, 398 species of mammals, approximately 17 000 species of flowering plants and 57 525 species of insects (Holthausen and Sawarkar 2002).

Much of India's wildlife is concentrated in Protected Area networks in the form of National Parks and Wildlife Sanctuaries. The remainder is distributed in Managed Forests under different forest divisions of the State Forest Departments. However, many species are unevenly distributed in pockets, most of which are quite small in area. As a result, each pocket of wildlife habitat can be viewed as an island surrounded by human settlements. Intense pressure on the land has resulted in loss and fragmentation of the habitat base available to wild animals, forcing them to seek alternate means of survival outside the forests. Further compounding matters, India hosts a cattle population of

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185.2 million (Report 2003a), the largest in the world. Many of the native cattle are not classified under any specific breed, and do not offer a high milk yield. Many also live on the forest fringes, competing for pasture with wild animals. This then leads to human-wildlife conflicts, which tends to culminate in a number of tragic outcomes, including wild animal poisoning.

India has an agriculture-based economy. Its gross domestic product (GDP) from agriculture and its allied sectors constitutes 19% of India's total economy (Report 2008a). The burgeoning population necessitates sufficient food production by the agricultural sector. However, the high temperature and humidity that is associated with a tropical country promotes the rapid multiplication of pests including insects, nematodes and fungi, which ultimately take a heavy toll on agricultural production. Thus, pest management is essential and chemical pesticides play an important role in increasing agricultural yields. After China, India ranks second in Asia, and twelfth in the world in terms of pesticide production (Mukherjee, Borad and Asnani 2006).

Among the pesticides used in India, insecticides account for 80%, followed by herbicides and fungicides (Abhilash and Singh 2009). This is in striking contrast to the global scenario, where herbicides account for the major usage followed by insecticides and fungicides (Abhilash and Singh 2009). Among the insecticides in use, organophosphorus compounds (OPC) have now overtaken the organochlorines (Gupta 2006). Carbamates and pyrethroids are used against pests that have developed resistance to OPCs. Among the carbamates, carbofuran is widely used either alone or in combination with the OPC phorate for most crops during sowing/planting. It has been listed among the pesticides most commonly used in India (Abhilash and Singh 2009).

As indicated by our colleagues in other parts of this book, pesticides have also been commonly used to poison wild animals in India. Poisoning is perceived as an easy way for people to rid themselves of troublesome animals, especially wildlife, without drawing too much attention to themselves. Numerous factors, including the type of agriculture conducted, public knowledge regarding toxicity of a specific product, cost, availability in the local market place and physical properties such as colour, taste and odour all determine the extent to which specific pesticides are used to deliberately poison animals. The fact that carbofuran (widely used as an insecticide/nematicide) is known to be highly toxic, is readily available in concentrated formulations, and is almost completely lacking in odour and taste automatically makes it a strong contender for selection as a poison (Gupta 1994; Elliott, Langelier, Mineau et al. 1996; Tataruch, Steinick and Frey 1998; Motas-Guzman, Marla-Mojica, Romero et al. 2003; Kwon, Wee and Kim 2002; Martinez-Haro, Mateo, Guitart et al. 2008).

4.2 Conservation measures and human-wildlife conflicts

India has been a pioneer in terms of the conservation of wildlife through the formation of sanctuaries. The Central Board for Wildlife was set up in India in 1952 and Project Tiger, launched in 1973 by the then Prime Minister Indira Gandhi, helped establish such areas and resulted in nine wilderness areas being set aside for tigers. A National Wildlife Action Plan was adopted in 1983 and three types of Protected Areas (PAs): Wildlife Sanctuaries, National Parks and Biosphere Reserves were created. As of 2002, there are 578 Protected Areas covering an area of 154 573 square kilometres or 4.70% of the total area of India (Rodgers, Panwar and Mathur 2002). However, the Protected Areas themselves are not uniform in size and are distributed unevenly throughout the country. A few of these areas span thousands of square kilometres, while more than 70% of them are smaller than 200 square kilometres.

It has been suggested that if the same total land mass had been protected but distributed over fewer protected areas, resident wildlife would have had a better habitat and would have been less susceptible to human disturbance. The Wildlife Institute of India (WII) has now divided the entire country into ten bio-geographical zones: Trans-Himalaya, Himalaya Desert, Semi-Arid, Western Ghats, Deccan, Gangetic Plain, Coasts, North East India, and Islands. The distribution of Protected Areas ranges from 2.20% in the Gangetic Plain to as high as 18.57% in the Islands (Rodgers, Panwar and Mathur 2002). This uneven distribution, combined with the fact that many areas are both small

and fragmented, increases the scope for human-wildlife conflict. Moreover, each Protected Area is actually now differentiated into a core and buffer zone for conservation and human use respectively. Hence, large parts of the buffer zones are often fragmented due to cultivation and human settlements (refer to Figure 4.1). Any damage to human property by wildlife within this buffer zone commonly results in retaliation against wildlife.

4.3 Types of human-wildlife conflict

The nature of the human-wildlife conflict in India in different regions depends upon the type of human settlements and species of wildlife present. The bio-geographic zones previously mentioned are all distinct in terms of their climate, topography, human settlements and wildlife pattern and thus the type of conflict is also varied in different regions (refer to Figure 4.1).

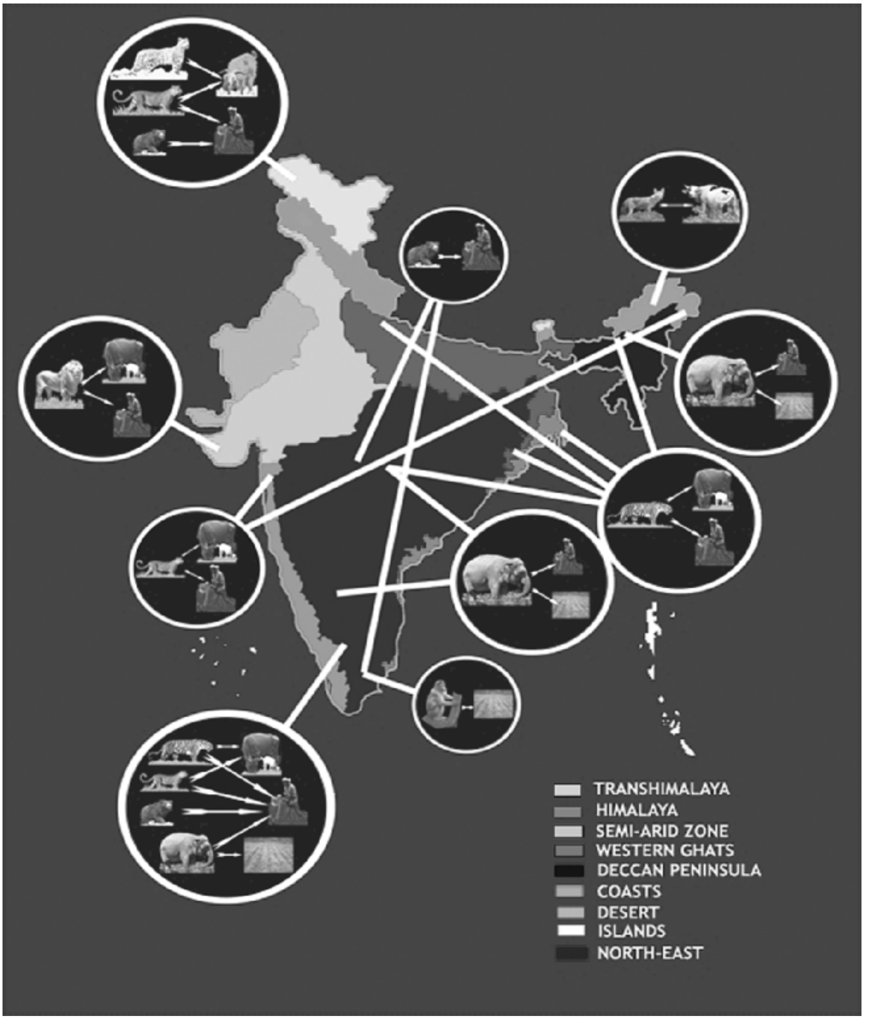

Figure 4.1 Zones of human-wildlife conflict in India

The two most pressing human-wildlife conflict situations that plague India today involve elephants and leopards. India holds the largest number of Asian elephants (*Elephas maximus*) in the world, but these creatures have lost much of their habitat and severe fragmentation has led to the destruction of corridors which they also use to move between fragments. Only 24% of corridors are under complete cover, and only 22.8% are without human settlements (Venkataraman 2005). Elephants cause damage to crops worth crores (i.e., tens of millions) of Indian rupees (Rs), and they are linked to the deaths of > 200 persons annually (Sukumar 1991). Elephants wander into human settlements, destroy crops, raid food stores, damage man-made structures, and occasionally injure or kill people in the process (Sarma and Easa 2006; Report 2009b). The eighth meeting of the steering committee of Project Elephant reported that 2 116 human deaths had been due to elephant encounters between 1991 and 2001. Elephants also face a threat from poaching (for tusks), but for this purpose, poachers usually resort to firearms rather than poisoning.

Attacks on humans by large carnivores have been attributed primarily to six species: tigers, lions, leopards, Himalayan black bears (*Ursus thibetanus*), sloth bears (*Melursus ursinus*) and wolves (Athreya, Thakur, Chaudhuri et al. 2004). With the exception of the leopard, all of these species are restricted within their habitats. The leopard is however more versatile (among these wild carnivores) and can adapt to diverse conditions. It is often observed within the core and in the buffer zones surrounding Protected Areas and Managed Forests. It can even survive in sugar cane plantations. It can tolerate human presence (to a point), and there have been several incidences where leopards have preyed on livestock, dogs, children and even adult humans. For further information on this, the reader is referred to Choudhury, Ali, Mubashir et al. (2008), where 73 attacks on humans involving leopards and 157 cases involving black bear are documented within the State of Jammu and Kashmir (in north western India). This article also discusses the circumstances and outcome of all 230 cases individually, although no information regarding retaliation through poisoning is provided. The Energy and Resource Institute and Uttar Pradesh Forest Development (TERI-UPFD) project annual report describes several types of conflicts including those involving elephant, wild boars (*Sus scrofa*) and monkeys causing damage to crops. They also note tiger-human and leopard-human conflicts in different parts of Uttar Pradesh (now Uttarakhand) State. Leopards have apparently killed 140 humans between 1988 and 2002 within the district of Pauri Garhrwal alone (Report 2003b).

A *Times* magazine article posted on 15 August 2004 estimated that between 30 and 40 people are killed annually by tigers in India. It also described another interesting conflict in the high mountains of Ladakh (a region in Jammu and Kashmir) between snow leopard (*Uncia uncia*) and pashmina goats (genus *Capra*) reared for their valuable fibres. Goat herders keep the animals outside at night in the cold to promote the development of soft thick hair, which is highly prized worldwide. However this practice makes it easy for the snow leopard to prey on them. Killing 20 or more animals at a time was apparently not uncommon, and a rather unbelievable record number was given as 107 (in same *Times* magazine article). Naturally, this killing frenzy by the snow leopards earns the displeasure of the goat herders (Sheikh, Rabgais and Ganai 2008). In a study that spanned two and a half years, Namgail, Fox and Bhatnagar (2007) estimated that snow leopards were responsible for about 38% of total livestock loss due to predation, primarily of domestic goats.

In the Itanagar Wildlife Sanctuary, Arunachal Pradesh State in northeast India, Ayyadurai and Varma (2003) recorded that a conflict involved wild dogs (*Cuon alpines*) and mithun (*Bos gaurus frontalis*). The mithun (a semi-wild bovid) was regularly preyed upon by wild dogs which hunt in packs with great efficiency. The reason cited for this predation was a poor natural prey base for the wild dogs (Ayyadurai and Varma 2003).

Other confrontations involve crop damage by Sambar deer (*Cervus unicolor*), Indian gaur (a type of wild cattle, *Bos gaurus*), nilghai (a type of antelope, *Boselaphus tragocamelus*), peacocks (*Pavo* sp.) and monkeys like macaques (*Macaca* sp.) and langurs (*Semnopithecus* sp.) (Figure 4.2).

Figure 4.2 Naughty macaques and langurs

Poaching elephants for ivory, rhinos for horns, large carnivores for skin, teeth and other body parts is not uncommon. However, again, for this purpose firearms are more commonly used rather than poisoning, mainly because instantaneous death is preferable so that the poachers can quickly collect the valuable body parts and make good their escape. Poisons used for this purpose need to be highly toxic, and carbofuran is potentially one good choice in this sense. However, no cases of carbofuran having been used for poaching have been recorded so far.

Table 4.1 presents the number of livestock, the human population and the type of conflicts present in and around different Tiger Reserves in India, as provided by Project Tiger, Government of India (http://Project tiger.nic.in).

Thus, the major human-wildlife conflicts afflicting different parts of India are:

- crop raiding by elephants, wild boars, other wild herbivores and monkeys;
- predation on cattle (and humans/accidents involving humans) by carnivores such as leopards, bears, wild dogs and tigers;
- damage to grains by birds such as the peacock.

The IUCN categorisation for these animals is presented in Table 4.2.

Most of the cattle maintained in the Nilgiris are Friesian crossbreds. In our experience, the animals preyed upon by tigers or leopards are healthy and often pregnant heifers in their prime age. Similarly, a recent survey (authors' own data) of Toda tribes in different villages revealed that predators posed the greatest threat to their buffaloes. Likewise, several animals that had been lost to predation were pregnant. Such losses create a negative attitude towards carnivores. Humans will then go to any extent in order to get rid of them. Several studies (see Table 4.3) have estimated that the economic loss caused by human-animal conflicts lies in the tens of millions of rupees (equivalent of approximately 225K USD).

Table 4.1 Human population, livestock population and type of conflicts reported in and around different Tiger Reserves of India (Source: http://projecttiger.nic.in)

Tiger Reserve	Human population in vicinity	Livestock population in vicinity	Type of conflict
Valmiki, Bihar	Not available	14 000	Predation on livestock
Palamau	39 000	70 000	Crop loss and predation on livestock resulted in poisoning, use of noose and fire arms
Bhadra, Karnataka	36 000	16 249	Crop raiding by elephants
Bandipur, Karnataka	160 000	180 000	Predation on livestock, poaching elephants for tusks
Nagarjuna, Andhra Pradesh	43 988	Core region: 43 988 Fringe region: 300 000	No conflicts reported
Namdapha, Arunachal Pradesh	2 000	500	Injury to humans by panther
Itanagar, Arunachal Pradesh	'Negligible'	250 per village	Wild dog preying on mithun
Manas, Assam	28 795	20 231	Humans killed and predation on livestock by tiger
Nameri, Assam	Information not provided	3 000	Crop raiding by elephants
Pench, Maharashtra	3 700	4 097	Crop raiding, depredation (no information on perpetrator)
Tadoba-Andhari, Maharashtra	41 000	41 820	Predation on livestock by tiger
Melghat, Maharashtra	20 000	15 642	Predation on cattle, injuries to human by tiger and sloth bear
Simlipal, Orissa	Core region: 576 Buffer region: 9 000	Core region: 400 Buffer region: 7 000	Crop raiding, poisoning
Periyar, Kerala	200 000	2 000	'Negligible'
Kanha, Madhya Pradesh	100 000	30 000	Predation on cattle by 'carnivores', damage to crops by 'herbivores'
Panna, Madhya Pradesh	4 000	8 658	Damage to crops, mauling of humans by sloth bear
Sariska, Rajasthan	Core region: 10 000 Buffer region: 35 396	Core region: 243 600 Buffer region: 142 998	Not available
Ranthambore, Rajasthan	Core region: 1 210 Buffer region: 3 055	Core region: 3 177 Buffer region: 25 000	Hunting of wildlife
Kalakkad, Tamil Nadu	10 000	100 000	Damage to crops by wild boar and bonnet macaque, sloth bear attacks on humans
Nilgiris, Tamil Nadu	Unknown	Unknown	Crop raiding by elephants, Sambar deer, Indian gaur and bonnet macaque Predation on livestock by leopard and tiger Injury and death of humans
Dudhwa, Uttar Pradesh	Unknown	Unknown	Poisoning of tiger recorded
Corbett, Uttaranchal	65 982	44 916	Man eating, poisoning of wildlife
Buxa, West Bengal	Not available	Not available	Trampling of human by elephant
Sundarbans, West Bengal	Not available	Not available	Killing of humans, poisoning of wildlife

Table 4.2 IUCN classification of species most commonly involved in human-wildlife conflicts in India

Animal	Category IUCN version 3.1	Schedule under Wildlife Protection Act of India, 1992	Remarks
Tiger (*Panthera tigris*)	Endangered	I	Only about 1 411 tigers are alive in the wild and populations show a decreasing trend
Leopard (*Panthera pardus*)	Near Threatened	I	Most incidences of conflicts are with humans
Elephant (*Elephas maximus*)	Endangered	I	Fragmentation of their habitat is the main threat, leading to incidences of crop raiding and trampling
Sloth bear (*Melursus ursinus*)	Vulnerable	I	Involved in second most human attacks, after the leopard
Snow leopard (*Uncia uncia*)	Endangered	I	Killing sprees lead to intense dissent among goat herders
Striped hyena (*Hyaena hyaena*)	Near Threatened	III	Scavenging behaviour leads to secondary poisoning
Vultures (*Gyps* spp.)	Least Concern to Endangered	I	
Bonnet macaque (*Macaca radiata*)	Least Concern	II	Present in large numbers and cause damage to crops
Wild boar (*Sus scrofa*)	Least Concern	III	

4.4 Regulation and management of human-wildlife conflict

Several governmental and non-governmental organisations (NGOs) as well as international bodies play an active role in the conservation of wildlife in India and in mitigating human-wildlife conflicts (Table 4.4). The Ministry of Environment and Forests, under the Central Government and the Department of Forest in various State Governments, are primarily responsible for the protection of wildlife. Legislation to protect wildlife and govern the use of pesticides is also in place under the Constitution of India. The Wildlife Protection Act of 1972 contains several procedures to deal with matters related to wildlife management. Poisoning is defined under Hunting, and is prohibited under Section 9 of Chapter III and punishable under the Act. It also deals with the declaration of Protected Areas (in the form of Sanctuaries and National Parks), and contains a list of different wild animals under six schedules. The Indian Forest Act also deals with laws relating to forests in terms of produce, felling of trees and other relevant duties.

The Insecticides Act was passed in 1968 to regulate the import, manufacture, sale, transport, distribution and use of insecticides with a view to preventing risks to human beings and animals. The Act (and the rules framed therein) make it compulsory to register pesticides with the Ministry of Agriculture, part of the central level of the Government of India. The granting of a license for manufacture, formulation and sale are dealt with at the State level. The Insecticide Rules of 1971 provide clear instructions with respect to the storage, use, packing and labelling, transport and disposal of

Table 4.3 Estimated loss of property due to conflicts in different Protected Areas throughout India

Region	Conflict	Estimated value of loss in rupees (Rs)	Recommendations and remarks
Nandadevi Biosphere Reserve, North India[a]	Crop damage by wild boar, bear, porcupine, monkey, musk deer, partridge Loss of sheep and goats to leopards	Crop: 538 620 Livestock: 1 024 520	Change in crop and cropping pattern, to high-value low-volume crops like medicinal plants Fair and quick disbursement of compensation Work to improve negative attitude of people towards reserve
Bhadra Tiger Reserve, South India (1996–1999)[b]	Crop damage by elephants Loss of livestock to tiger	Crop: 11 percent of annual grain production (0.82 tonnes per family) Livestock: 12 percent of total holding (0.9 head per family)	Improved compensation scheme Provision of crop and livestock insurance
Ranthambore Tiger Reserve, Rajasthan[c]	Loss of livestock to tiger		Use of crossbred cattle to increase efficiency of their milk production Use of bio-gas instead of wood from forest as fuel Controlled grazing involving local village men
Gya-Miru Wildlife Sanctuary in Ladakh, Jammu and Kashmir[d]	Loss of domestic livestock (sheep, goats, yak and horses) to snow leopard (*Panthera uncia*), Tibetan wolf (*Canis lupus chanku*) and Eurasian lynx (*Lynx isabellina*)	ca 8 600 Rupees, equivalent to 190 USD per household per year	No recommendations offered

[a]Rao et al. (2002)
[b]Madhusudan (2003)
[c]Ward (1994)
[d]Namgail, Fox and Bhatnagar (2007)

pesticides. They also give details to be incorporated on the packaging as well as the leaflets that should accompany each pack of pesticide (shown in Figure 4.3). The skull and crossbones and the word 'poison', marked in red, indicate that carbofuran is an extremely toxic insecticide, belonging to Category I. This category contains pesticides with a lethal dose (LD_{50}) of 1 to 50 milligram per kilogram body weight and 1 to 200 milligrams per kilogram body weight for oral and dermal routes respectively. The species used to establish toxicity are not indicated.

To assist people from different regions of India (who speak different languages), the label and leaflets affixed or attached to a package containing an insecticide are printed in Hindi, English and in several other regional languages, usually at least four or five, in use in the areas where the package is likely to be stocked, sold or distributed. However, it remains possible that some farmers do not

Table 4.4 Legislation and organisations for conservation of wildlife in India

Type	Purpose
Legislations	
The Wildlife [Protection] Act, 1972	An Act to provide for the protection of [Wild animals, birds and plants] and for matters connected therewith or ancillary or incidental thereto.
Indian Forest Act, 1921	An Act to consolidate the law relating to forests, the transit of forest-produce and the duty leviable on timber and other forest-produce.
Insecticides Act, 1968	An Act to regulate the import, manufacture, sale, transport, distribution and use of insecticides with a view to prevent risk to human beings or animals, and for matters connected therewith.
Foreign Trade (Development and Regulation) Act, 1992	Provides guidelines framed for export and import policy. Prohibits import of wild animals including their parts. Prohibits export of wild animals and their derivatives.
Prevention of Food Adulteration Act, 1954	An Act under the Ministry of Health and Family Welfare to take care of safety of food.
Government Bodies	
Project Tiger	Project under implementation since 1973 to ensure a viable tiger population in India through wildlife management and protective measures.
Project Elephant	Launched in February, 1992 to assist States having free-ranging populations of wild elephants to ensure long-term survival of identified viable elephant populations in their natural habitats.
Project Rhino	Launched in 1980 at Kaziranga National Park to save the one-horned rhino from extinction.
The Gir Lion Project	Launched in 1972 to protect the last surviving Asiatic lions.
National Tiger Conservation Authority	Authority under the Ministry of Environment and Forests to conserve tigers.
Special Tiger Protection Force	A special trained force proposed by the Ministry of Environment and Forests to protect tigers.
Tiger Task Force	A body under the Ministry of Environment and Forests to review management of Tiger Reserves.
Non–Governmental Organisations (NGOs)	
World Wide Fund for Nature, India	Founded in 1968 with the objective of ensuring the conservation of wildlife and wildlife habitats.
Wildlife Trust of India	A non-profit conservation organization committed to initiating and catalysing actions that prevent the destruction of India's wildlife and its habitat
Bombay Natural History Society	Largest NGO in the Indian subcontinent engaged in nature conservation research.
Save the Tiger Fund	Funds different projects to conserve tiger and its habitat.
International Conventions for which India is a signatory	
The Convention on International Trades in Endangered Species of Wild Flora and Fauna (CITES), Washington	
Convention on the Conservation of Migratory Species of Wild Animals, Bonn	
Convention on Biological Diversity Conservation, Rio De Janero	
Trade Record Analysis of Flora and Fauna (TRAFFIC)	
Convention Concerning the Protection of the World Cultural and Natural Heritage	
Convention for the Protection of Birds Useful to Agriculture, 1902	
International Convention on the Protection of Birds, 1950	
Convention on the Wetlands of International Importance especially as Waterfowl Habitats, Ramsar	

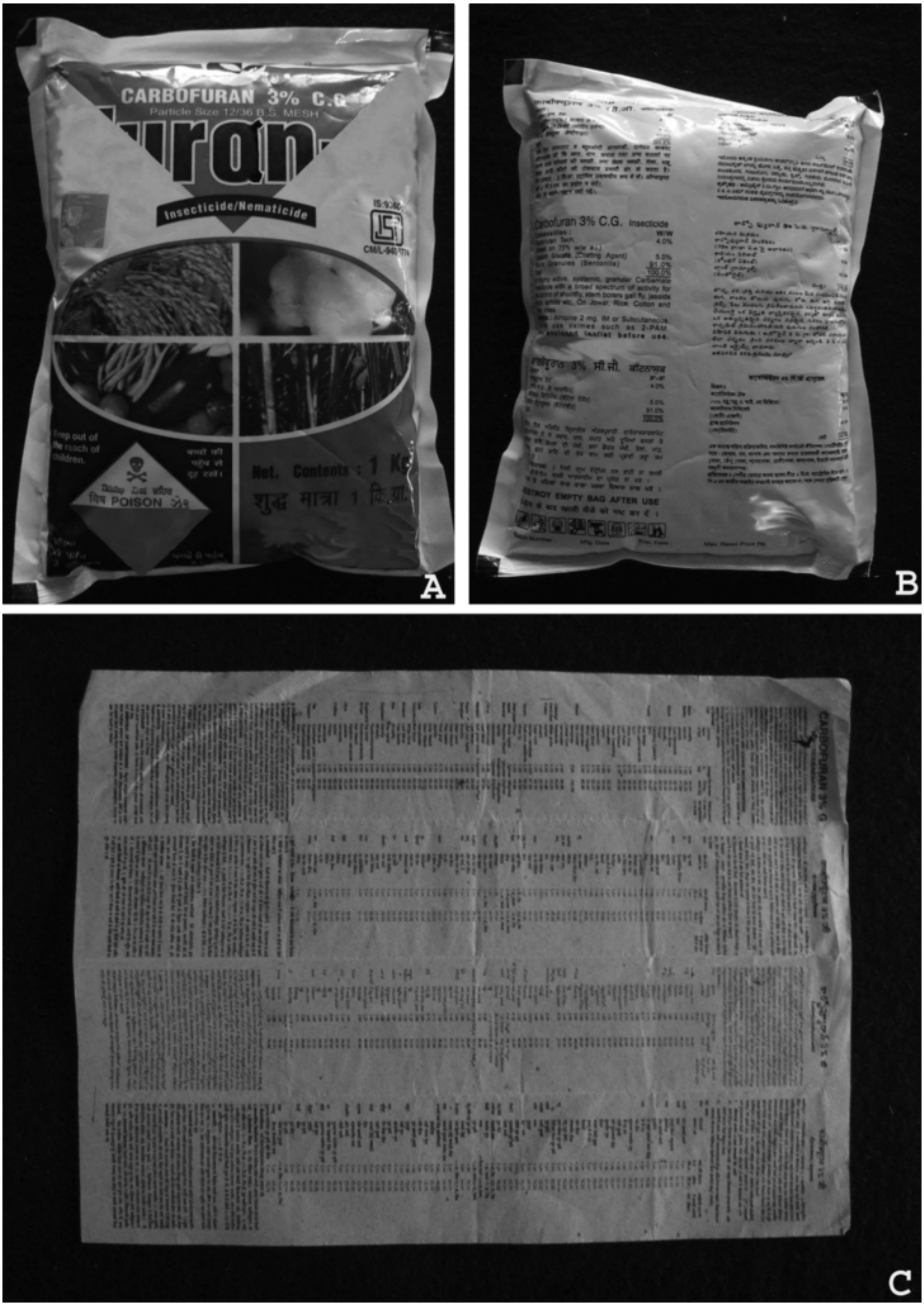

Figure 4.3 Sample carbofuran packaging and leaflet

understand any of the languages on the packages. The leaflet must provide all the necessary details with respect to correct usage, toxicity, antidote(s), proper method of storage and disposal of containers as well as other common names of the compound, as per the Insecticide Rules.

Project Tiger and Project Elephant are two successful wildlife conservation projects funded by the Government of India. Project Tiger currently functions in 27 States and Project Elephant functions in 12 States within the country. Even though these projects were basically meant to protect two species, their objective is to improve the habitat of wildlife in general. Funding tends to be diverted towards compensation for loss of human life, livestock and crop, habitat management (in the form of compensation for relocation or rehabilitation of villages in the core and critical zones of Protected Areas), capacity building (for field staff) and strengthening anti-poaching activities. NGOs are also involved extensively in several wildlife conservation activities such as: compensating for loss of wildlife, rehabilitation of affected animals, monitoring threatened species and providing training for local communities to deal with wildlife in a less conflictive manner.

4.5 Use of carbofuran in India

Carbofuran was first registered for use in India as a pesticide in 1974, as per the Insecticide Act of 1968. The Act provides a list of nine international companies from which carbofuran can be imported. Registered formulations of carbofuran are also manufactured within the country at Valsad. The formulations registered for use within India are Carbofuran 3% CG and 50% sp. The import, manufacture and use of Carbofuran 50% sp is allowed only for ‘governmental purposes’, otherwise its use is banned. While the term ‘governmental purposes’ is not actually defined within the Act, it is taken to mean that it should be used to prepare standards for analyses in forensic laboratories (for example), however this is a matter for speculation.

Table 4.5 summarises the uses of carbofuran and its commercial preparations and formulations that are registered in India. The 3% CG granule formulation is most frequently used and is commonly available in the market in 1, 3 and 5 kilogram packs. This formulation is sold under several brand names: Furadan, Fury, Hexafuran, Furatox, Agrofuran, Furon-G, Hammer 3G, Carbomain, Anufuran, Carbocial and Tatafuran. The cost for granules varies between 65 and 80 rupees per kilogram of formulation (which equates to approximately 1.5 and 2 USD).

In India, carbofuran is used as a systemic insecticide/nematicide on a variety of crops including cereals, vegetables, pulses and cash crops like tea and banana. The rate of application recommended by the manufacturer varies from 16 to 100 kilograms of formulation per hectare, depending on the crop and the pest species targeted. The most common mode of granule application is within the soil, while planting or sowing. In certain crops warranting a top dressing, (i.e., an application after the crop has germinated), the pesticide is then sprayed using a granule applicator or broadcast by hand.

The 3G formulation is the most popular granular insecticide in India (Khan 2008). Its common uses are to control grubs and nematodes in cotton and sucking pests such as leafhoppers (family Cicadellidae) and stem borers (Scirpophaga spp.) in rice, sugarcane, fruits and vegetables. The application of carbofuran has also yielded some unexpected benefits. Its application to rice rhizosphere soil suspensions was (for example) found to stimulate autotrophic oxidation of ammonium (Ramakrishna and Sethunathan 1982). This effect was found to be more pronounced with Furadan than with technical grade (or pure) carbofuran (Ramakrishna and Sethunathan 1982). When applied to eggplant (*Solanum melangena*), Furadan was also found to increase the yield from the crop and improve the availability of nitrogen, phosphorus and sulphur in the soil (Khandkar, Shrikhande and Shinde 1994).

Table 4.5 Details of carbofuran pesticides registered for use in India

Classification under Insecticide Act 1968	Registered for use as pesticide[a]
Presentation	1, 3 and 5 kg granules
Trade names	Furadan, Fury, Hexafuran, Furatox, Agrofuran, Furon-G, Hammer 3 G, Carbomain, Anufuran, Carbocial
Cost	60 to 80 Rs[b] for the 1 kg formulation
Composition	Carbofuran (active ingredient 3 %) along with coating agent (calcium silicate) and black granules
Crops for which indicated	Apple, banana, bajra[c], barley, beans, brinjal[d], carrot, citrus fruits, cotton, groundnut, jowar[e], jute[f], lemon-grass, maize, okra, paddy wheat, pea, pepper, potato, soya, sugarcane, tea, tobacco, yam
Dosage of application	16 to 100 kg of the formulation per hectare
Classification as per Insecticides rules 1971	Category I (extremely toxic)

[a]The other formulation, Carbofuran 50 sp, is banned for import, manufacture, and use as a pesticide in India
[b]Rupees, the equivalent of ca 1.30 to 1.70 USD
[c]A type of millet
[d]A type of aubergine/eggplant
[e]A type of sorghum
[f]Plant fiber typically used to make rope and sacking

4.6 Use of carbofuran in relation to other compounds

The tendency toward lower persistence for OPCs and carbamates such as carbofuran in the environment is a major factor influencing their market uptake and use over more persistent compounds such as organochlorines. Current work indicates that more 'environmental' damage is thought to have been caused within India because of the use of persistent compounds such as hexachlorocyclohexane (HCH), DDT, endosulfan and phorate than by carbofuran (Abhilash and Singh 2009). Residue levels for persistent organochlorines, such as HCH isomers (BHC: 1,2,3,4,5,6-hexachlorocyclohexane), DDT compounds [1,1,1-trichloro-2,2-bis (p-chlorophenyl) ethane], polychlorobiphenyls (PCBs) and hexachlorobenzene (HCB) continue to be measured in a number of Indian wildlife species (Ramesh, Tanabe, Kannan et al. 1992). For example, high levels of HCH and DDT in the tissues of pond herons (*Ardeola grayii*) and cattle egrets (*Bubulcus ibis*), which feed in agricultural fields, have been reported. Realistically, many remain of the opinion that for the majority of pesticides, when properly applied as per the manufacturer's specification, significant injury to wildlife tends to be rare (Cooper 1991).

4.7 Diagnosing carbofuran poisoning in India

Confirmation of carbofuran poisoning in wildlife requires careful investigation. Information can be gained from circumstantial evidence, postmortem examination, sampling, and chemical analyses (for the specific etiological agent). Typical cholinergic symptoms observed in living animals are detailed in Chapter 2. When dead animals are found, historical data regarding the type of bait recovered, any known human-animal conflicts in the region, circumstantial evidence (e.g., containers

or packaging for pesticides and/or the visible presence of granules in the bait), will be of immense use when determining whether poisoning took place. Some of this information can also be obtained through inquiries made in nearby villages.

As veterinarians, we the authors have come across several cases of accidental and malicious exposure to carbofuran or OPC compounds in domestic cattle. The pain/agony which an animal undergoes after ingestion of a cholinesterase (ChE) inhibitor has to be seen in order to fully grasp its extent and severity. A prognosis will depend on the amount of poison that has been ingested. Common symptoms/effects noted are classified as 'muscarinic' (of the toxic alkaloid muscarine), 'nicotinic' (having an affinity for nicotine compounds) and central. The muscarinic effects include hypersalivation, miosis (constriction of the pupils), frequent urination, colic, diarrhoea, bradycardia (slowed heartbeat), and dyspnoea (breathlessness), in which breathing by mouth is often noticed. Nicotinic effects include muscular fasiculations (involuntary muscular contractions) and weakness, and central effects are indicated by nervousness, ataxia (lack of muscular coordination) and seizures (Cheeran 2007). These common symptoms are caused by the accumulation of acetylcholine which follows cholinesterase inhibition by OPCs or carbamates. A positive response to parenteral administration (i.e., through the vein) of atropine sulphate can be very dramatic.

As discussed in Chapter 2, the mode of inhibition of cholinesterase caused by carbamates and OPC differs: carbamate-induced inhibition is reversible, while OPCs essentially inhibit the enzyme irreversibly. Consequently, the cause of poisoning must ideally be confirmed before treatment with an oxime is initiated. In fact, the possibility that a potential treatment will further confound the toxic effects makes it essential that a specific diagnosis of the etiological factor is made in any suspected case of poisoning. Cheeran (2007) suggests several precautions that should be taken when treating wild elephants exposed to suspected poisons. The reader is referred to this work for further information and general guidelines regarding poison diagnosis and treatment in elephants.

In India, samples tend to be submitted separately, in sealed containers containing a saturated salt solution (along with a control container with salt solution alone). Samples commonly collected include the brain, liver, kidney, stomach, intestine and lung, as well as stomach and intestinal contents and the suspected bait used (sampled from the carcass or any other source of exposure). Circumstantial evidence in the form of packaging or containers found in the vicinity is also provided where possible. When a carcass has been exhumed, the soil beneath the gastrointestinal tract is sampled, as is any ash (if the carcass has been burnt). The quantity of sample collected must be sufficient for confirmation and quantification. As a general guideline, Cheeran (2007) suggests collecting 1 kilogram of liver and a proportionate amount of other tissue.

Several authors have suggested using the brain cholinesterase reactivation technique to confirm exposure to carbofuran and differentiate this exposure to that of other OPC compounds (Smith, Thomas and Hulse 1995; Elliott, Langelier, Mineau et al. 1996). At postmortem, the pattern of cholinesterase reactivation changes, and knowledge regarding normal values for different species of wildlife are required in order to reliably use this technique. Collecting a sample of brain (in a partially frozen state) which is suitable for such analysis requires an experienced taxidermist. However, in India, we lack both the laboratory facilities and the skilled manpower required to perform the cholinesterase reactivation test for confirmation of carbofuran ingestion.

In India, most wildlife necropsies are conducted by wildlife veterinarians posted within Protected Areas. However, conflicts do occur in other Managed Forests where local veterinarians are responsible for conducting necropsies. Attending veterinarians must be sufficiently trained to investigate a given case of poisoning, especially with regard to collecting and sending samples as required by a Forensic Laboratory. Cheeran (2007) again provides details regarding the procedure which should be used to collect samples for analysis of different types of wildlife poisoning.

Kholkute (2003) has also described the precautions that should be taken when submitting samples to a State Forensic Laboratory. Bottles containing tissue samples, and the accompanying

letter, should be sealed with a tamper proof metal seal (to ensure the sample is not tampered with). Bottles should be numbered, and the letter must follow a prescribed format, and provide the name and a description of the samples written against each number. The recommendation is to send 600 to 800 grams of sample for chemical analyses (Kholkute 2003). One concern is that any carbofuran present could go unnoticed if it were to undergo rapid breakdown due to metabolism (refer to Figure 1.9 in Chapter 1). Consequently, cooperation between individuals conducting the necropsy, and the laboratory in which the samples are to be analysed, is essential to ensure the samples are processed in good time.

4.8 Forensic facilities and analyses in India

Most samples collected in India are sent to forensic laboratories for analysis and determination of poisoning. To ascertain the presence of carbofuran, the sample is extracted with chloroform or hexane and subsequently analysed by thin layer chromatography (TLC, described in Chapter 1) using a hexane-acetone or benzene-chloroform-ethyl acetate system. Titration is achieved using bromocresol green as an indicator for quantification. Carbofuran identification in bait, stomach contents, liver and kidney are considered confirmative of poisoning. GC/MS is used to confirm the presence of a poison, once a sample tests positive by TLC.

Tewari and Ravikumar (2000) have described the history and development of forensic laboratories in India. By 1990, most Indian States had their own State Forensic Laboratories (SFL) and there were also Regional Forensic Laboratories (RFL) in major cities. Three Central Forensic Laboratories (CFL) take care of research and development, and analyse cases from States/Union Territories that do not have a forensic laboratory. The Central Forensic Laboratories have better facilities, and can act in place of State Forensic Laboratories to solve complex investigations (Tewari and Ravikumar 2000). However, many Regional Forensic Laboratories themselves are located some distance from certain Protected Areas where investigations regarding wildlife poisonings are carried out/required. This creates difficulty when submitting samples to the relevant laboratory, and only cases with clear circumstantial evidence tend to be sent for poison confirmation. The difficulties posed by geographical distance, and a lack of transport infrastructure can unfortunately make toxicological analysis ‘optional’. Consequently, cases of poisoning that do not offer sufficient evidence on the ground certainly go undiagnosed. The Wildlife Institute of India Forensic Laboratory (www.wii.gov.in), and other laboratories in various educational institutions related to veterinary science (at the Indian Veterinary Research Institute (IVRI; www.ivri.nic.in) in Bareilly, for example) also help investigate wildlife crime.

Regional Forensic Laboratories have a predetermined list of OPC and carbamate compounds to screen for, in addition to carbofuran:

1. Acephate
2. Anilofos
3. Chlorfenvinphos
4. Chlorpyrifos
5. Diazinon
6. Dichlorvos (DDVP)
7. Dimethoate
8. Edifenphos

9. Ethion
10. Fenitrothion
11. Fenthion
12. Formthion
13. Kitazin
14. Malathion
15. Methyl parathion
16. Monocrotophos
17. Phenthoate
18. Phosalone
19. Phosphamidon
20. Profenofos
21. Quinolphos
22. Temephos
23. Thiometon
24. Triazophos
25. Trichlorphos

This list is interesting in that it provides an insight into the other compounds in use and potentially of concern within India. Readers should note that this list is provisional and additional pesticides (e.g., phorate) can be screened upon request, when warranted by circumstantial evidence.

4.9 Case studies: use of carbofuran for poisoning in relation to other compounds

In India, certain important factors tend to determine whether or not a given pesticide is used as a poison. Such factors include (1) whether or not the public is aware that the compound could be used for this purpose, (2) the type of agriculture present (which determines the type of pesticide on hand to use as a poison), (3) availability, (4) cost, (5) toxicity of the commercial preparation and (6) how likely it is to be detected by target wildlife (through its physical properties such as colour, odour and taste). On the basis of these criteria, carbofuran is perceived as a suitable choice for poisoning. Incidents of lethal exposure to any pesticide could result from accidents during normal use, from misuse, or abuse.

4.9.1 Accidental exposure

While accidental poisoning incidents in humans and animals have been reported in and around India, there are relatively few reports regarding accidental poisoning with carbofuran. However, many of those that have been reported are significant. In 1984, a now infamous accidental leak of poisonous

methyl isocyanate gas (an intermediate in the production of carbamate pesticides discussed in Chapter 1), occurred at a plant in Bhopal, Madhya Pradesh. More than half a million people were affected, about 50 000 permanently disabled and about 10 000 lost their lives (Ipe 2005). Bhopal is considered the worst chemical disaster in India, and certainly one of the worst chemical disasters in the world. Twenty-five years on, health centres in the area still receive people who suffer from various ailments caused by the incident (Report 2009f).

Bhattacharyya, Lahiri, Chattopadhyay et al. (2002) have analysed data from 140 children admitted for poisoning in a rural hospital in West Bengal. They found that 18.4% of cases were caused by carbamate pesticides, and 50% were caused by OPCs. Furadan, Rogor (dimethoate 30%) and Tara 909 (active ingredient: dimethoate) were the carbamates involved. All cases were accidental, except one, where an adolescent poisoned his 12-month-old step-brother. Levin (1991) has also tabulated three incidents of accidental intake of pesticide-treated seed grain by humans in India. In these cases, the pesticides involved were BHC and methyl parathion. Some incidents of accidental exposure in humans to pesticides (including carbofuran) are presented in Table 4.6.

One noteworthy accidental exposure incident (in 2008) has involved free ranging domestic cattle. In this case, a cow ingested mowed grass from a golf course lawn that had been treated with carbofuran. Since the golf course was situated right in a reserve forest, there was also a considerable chance that other wild herbivores (like Sambar and barking deer (*Muntiacus muntjac*)) could have had access to the pesticide-laced grass. Once carbofuran enters the food chain, organisms at higher trophic levels, such as tigers and other scavengers, can be secondarily exposed. To ensure domestic animal safety, the golf club authorities were informed of the incident and local cattle owners are now warned well in advance when any pesticide application is due to occur. However, this measure is obviously not sufficient to protect wildlife since their movements cannot be controlled. Instead, pesticide use should really be restricted in wildlife-sensitive areas.

Table 4.6 Known/reported incidences of human poisonings with carbofuran and other compounds in India and southern Asia

Year	Location[a]	Pesticide(s) involved, as reported	Number affected	Mode of poisoning	Reference
1984	Bhopal, Madhya Pradesh	Methyl isocyanate (an intermediate in carbamate production)	More than 5 lakh[b], with 50 000 permanently disabled and 10 000 deaths	Accidental	Ipe (2005)
2000	Tamluk, West Bengal	OPC[c], carbofuran, endosulfan pyrethroids, fungicides	140 cases throughout the year	Accidental, except for an incident where a baby was poisoned by step-brother	Bhattacharyya, Lahiri and Chattopadhyay (2002)
2009	Dhamrai Upazila, (Bangladesh)	Carbofuran (Furadan) and OPC[c]	3 children died	Excessive application in agricultural field	Report (2009b)
2009	Salem, Tamil Nadu	Phorate	6 children died	Deliberate use	Report (2009e)

[a]Unless otherwise indicated all locations provided are in India
[b]A unit of 100 000, five lakh equates to 500 000
[c]Organophosphorus compounds

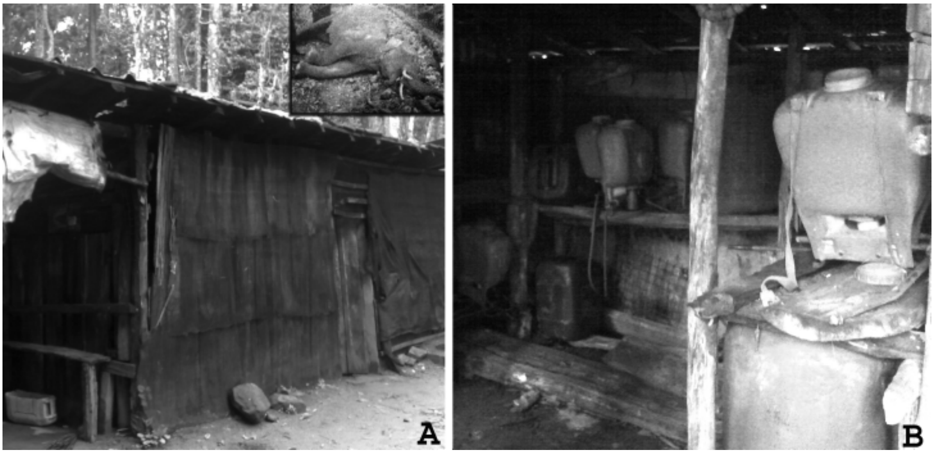

Figure 4.4 Storage shed at tea estate that was raided by elephants

In another accident, carbofuran was responsible for the death of two elephants. The incident was reported in a tea estate in Valparai, which is located in the Western Ghats. This area is well known for its rich biodiversity (Report 2009b). Elephants in the region are in the habit of looting provision stores in search of salt and other grain (see Figure 4.4). In this case, a herd of seven elephants destroyed a shack belonging to the tea estate and consumed vegetable matter and other leftovers held inside. The shack was also used by workers on the tea estate to store fertilisers and equipment for their application (as well as personal belongings and utensils used to prepare cups of tea). Furadan granules were consumed by two elephants, which succumbed to poisoning. In this instance, suspicion regarding Furadan was initially based on circumstantial evidence. The presence of carbofuran in the viscera of both elephants was subsequently confirmed at The Regional Forensic Science Laboratory at Coimbatore (Report 2009b). In our opinion, the Insecticide Rules of 1971 actually provide sufficient guidelines on the safe storage of pesticides to prevent such incidents, and hence this accident should not have occurred.

Avian poisoning, due to ingestion of seeds treated with pesticides, is very common worldwide (see also Chapters 7 and 8). For example, Pain, Gargi, Cunningham et al. (2004) described one such incident, where 15 Sarus cranes (*Grus antigon*) and three common cranes (*Grus grus*) were poisoned by monocrotophos at Bharatpur reserve forest in India. Carbofuran granules have been extensively used with seeds in India, and many birds could be regularly exposed, despite there not being any reported incidences to date. Panda and Sahu (2009) have studied the effect of carbofuran on a dominant crop field earthworm (*Drawida willsi*) in a rice field. They found that a single and double dose application of carbofuran (1.1 and 2.2 grams per kilogram of active ingredient) resulted in a reduction of 17 and 23% in earthworm biomass, respectively. In this case, a secondary repercussion would be that the prey base for birds would also be compromised.

4.9.2 Misuse of carbofuran

The second type of exposure, through carbofuran misuse, is a major cause for concern in India. Even though the dosage which should be used for different crops and pests is clearly indicated in the leaflet that accompanies the formulation, it is often the suppliers who advise farmers on the application rate.

The farmers themselves also adjust the dosage (and, anecdotal evidence indicates, use more than the recommended level) when they are not satisfied with the results. As mentioned elsewhere in this book (e.g., Chapters 6, 7 and 8 on the UK/Republic of Ireland, Latin America and the United States/Canada, respectively), carbofuran is also used in combination with organophosphate compounds. In India, it is used with phorate, and in such cases, the dosage increase has that much greater potential to do harm. In one incident, a newspaper report from Bangladesh (Report 1999) described the death of more than 5 000 sparrows in Dakatia village (located near the Indo–Bangladesh border) on a single day in August 1999. This was reportedly due to the excessive use of pesticides, including Furadan, in an agricultural field. In another incident (also in Bangladesh), three children and several domestic animals reportedly died due to an over-application of carbofuran (Report 2009c). Here the children had been playing with clay from the pesticide-treated field.

As mentioned in Chapter 2, carbofuran is absorbed intra-dermally and also through inhalation. Most farmers in India do not wear sufficient protective gear while handling pesticides (Abhilash and Singh 2009). In fact, it seems that they tend to ignore or have become used to the discomforting symptoms that follow low-grade exposure (such as nausea, headache and light-headedness) from which spontaneous recovery, due to the reactivation of the cholinesterase enzyme, occurs in one to four hours (Baron 1991). To minimise direct contact for those handling the pesticide, Rallis India (a major marketing agent for Furadan) packs the granules in a flexibag. This bag (Hassia flexibag 250) offers greater size variability, enables tamper-proof packing of the carbofuran, and considerably reduces spillage.

Abhilash and Singh (2009) reviewed the current status of pesticide usage in India and have provided recommendations to prevent problems caused by the misuse of pesticides. They list several factors including illiteracy, lack of protective equipment, poor application practice and excessive usage of pesticides. Such issues are more prevalent in India than in developed countries and thus the risk of exposure increases.

4.9.3 Deliberate poisoning using carbofuran and other compounds

In terms of the abuse of carbofuran for deliberate poisoning, either in human suicide attempts or in attempts to kill animals, other chapters in this book demonstrate that carbofuran has been frequently used to poison wildlife worldwide, and India is no exception (Gupta 1994). As we noted in Section 4.9, the granular form in which carbofuran is produced, its lack of odour, and its potent toxicity all make it an easy choice for use in poisoning. However, the number of documented cases of deliberate poisoning with carbofuran in India is currently low, when compared to other pesticides. Instead, OPC pesticides have been preferentially employed for this purpose (refer to Table 4.7).

Awareness regarding the potential to abuse this pesticide has increased, especially after the recent ‘60 Minutes’ television piece on lion poisoning in Kenya with Furadan (Chapter 3 provides a further description of the piece). However, very few incidents of deliberate poisoning using carbofuran have been reported in India. Pinakini and Kumar (2009) diagnosed one case of carbofuran poisoning in a human (one individual) quantitatively, using serial cholinesterase estimation. Recently, a newspaper (Report 2009e) reported that eight children had been deliberately poisoned using phorate. Those involved (self-proclaimed soothsayers), poisoned the children solely to ‘prove’ their skills of prophesy and clairvoyance.

In a study of all emergency admissions (33 207 patients) to a hospital in Mangalore city, Singh and Unnikrishnan (2005) found that acute poisoning constituted 1.0% of cases seen. Of this, 70% of the cases were males, and the majority (36%) were between 21 and 30 years of age; 72% of poisonings were intentional and agrochemical pesticides were used in 49% of them (followed by drugs and alcohol). The major pesticides involved were OPCs and aluminum phosphide. No mention of carbofuran was made in this report (Singh and Unnikrishnan 2005).

Table 4.7 Pesticide poisoning incidences reported in Indian and South Asian wildlife

Year	Location[a]	Pesticide(s) involved, as reported	Species affected	Number of deaths	Type of Poisoning	Reference
1999	Dakatia village, Jessore (Bangladesh)	Several, including Furadan	Sparrows (*Passer domesticus*)	> 5000	Application of excess quantity in field	Report (1999)
2000	Keoladeo National Park, Bharatpur, Rajasthan	Monocrotophos	Cranes (*Grus* spp.)	18	Accidental intake of laced seeds	Pain et al. (2004)
2001	Nameri National Park and Tezpur, Assam	Demecron	Asian elephant (*Elephas maximus*)	14	Deliberate, along with liquor and pumpkins	Gureja et al. (2002)
2001	Mudumalai, Tamil Nadu	'Pesticides'	Hyena (*Hyaena hyaena*)	1	Secondary	Report (2001)
2003	Sandynallah Reserve Forest, Nilgiris, Tamil Nadu	Carbofuran (Furadan)	Leopard (*Panthera pardus*)	1	Deliberate, cow carcass laced with carbofuran	Venkataramanan et al. (2008)
2005	Pudukottai, Tamil Nadu	Carbofuran	Bonnet macaque (*Macaca radiata*)	53	Deliberate	Report (2005)
2007	Kaziranga, Assam	Malathion	Bengal tiger (*Panthera tigris*)	2	Deliberate	Talukdar, Haziraka and Buragohain (2008)
2008	Nilgiris, Tamil Nadu	Phorate	Bengal Tiger (*Panthera tigris*)	1	Secondary	Kalaivanan et al. (2010)
2008	Sonitpur, Assam	Carbamate	Asian elephant	3	Deliberate	Arora (2008)
2008	Pudukottai	Zinc phosphide	Bonnet macaque	31	Deliberate	Muruganandan, Umarani and Paramasivam (2010)
2009	Karimnagar, Andhra Pradesh	'Pesticide'	Peacock (*Pavo cristatus*)	19	Deliberate, pesticide laced seed	'News paper report', specific report not mentioned
2009	Udhagamandalm, Tamil Nadu	Zinc phosphide	Jungle myna (*Acridotheres fuscus*)	16	Secondary	Report (2009a)
2009	Nilgiris	Phorate	Black panther (*Panthera* spp.)	1	Secondary	Kalaivanan et al. (2010)
2009	Walparai, Tamil Nadu	Carbofuran (Furadan)	Asian elephant	2	Accidental	Report (2009b)
2009	Assam	'Pesticides'	Vultures (*Gyps* spp.)	21	Secondary	WTI News report (2009)
2010	Nilgiris, Tamil Nadu	Methyl-isoparathion	Sloth bear (*Melursus ursinus*)	1	Deliberate	Report (2010)

[a]Unless otherwise indicated in brackets, all locations provided are in India

Table 4.7 details poisoning incidences in wildlife in different parts of the country. Venkataramanan, Sreekumar, Kalaivanan et al. (2008) recently confirmed that carbofuran was used to poison a leopard (*Panthera pardus*) in the Nilgiri Biosphere Reserve. The leopard in question was known to have killed several cattle. Subsequently, the carcass of a cow was laced with Furadan granules. An empty Furadan bag discovered in a bush adjacent to the cow carcass provided circumstantial evidence. Muscle tissue from the thigh region of the baited cow carcass, stomach contents, liver and kidney from the leopard carcass and washes from the empty cover all contained traces of (unmetabolised) carbofuran (Venkataramanan, Sreekumar, Kalaivanan et al. 2008). This was confirmed through chemical analyses at the State Regional Forensic Laboratory (RFSL) in Coimbatore, Tamil Nadu.

In another investigation, into the death of 53 bonnet macaques (*Macaca radiata*, 32 males and 21 females) at Pudukottai, Tamil Nadu, carbofuran poisoning was shown to be the cause of death (Report 2005). A group of monkeys, which were damaging a ground nut crop, were poisoned by a farmer. First, the monkeys were acclimatised to feeding on a mixture of rice flour, jaggery (crude sugar) and mashed ground nut. Once the monkeys were accustomed to this mixture, it was laced with carbofuran. Tissues from the monkey carcasses tested at the State Regional Forensic Science Laboratory, Trichy in Tamil Nadu, were positive for (unmetabolised) carbofuran (Report 2005).

Other wildlife related incidents, including those involving additional agents, are presented in Table 4.6, which shows that OPC pesticides have been extensively used for poisoning. Gureja, Menon, Sarkar et al. (2002) reported on an incident at Nameri National Park and Tezpur, Assam in which 22 elephants were suspected to have been poisoned. Fourteen of these were confirmed to have been poisoned with the OPC demecron. On one side of one of the dead elephants, the words 'paddy thief Bin Laden' had been written with white paint in Assamese (the local language) as an expression of anger. The elephants were attracted by country-made liquor and ripe pumpkins. These treats were used as bait and laced with demecron, which was readily available in fertiliser shops (Gureja, Menon, Sarkar et al. 2002). Cheeran (2007) has also reported that 49 elephants were killed by poisoning in different States across India. Assam sustained 29 deaths, the highest number among the 11 States listed.

Talukdar, Haziraka and Buragohain (2006) have also documented the deliberate poisoning of whistling teals (*Dendrocygna javanica*) for human consumption in Bokakhat, Assam. These birds were poisoned by paddy impregnated with quinal phosphate, which slows the birds' reflexes and makes them lethargic. The toxin is reportedly non-lethal to humans.

In another incident, in April 2010, the highly putrefied carcass of a sloth bear was found on a tea estate in the Coonoor Range in Udhagamandalam, Tamil Nadu. The maggots collected from the carcass, and the fluid mixed with soil beneath the carcass tested positive for methyl-isoparathion at the Regional Forensic Science Laboratory, Coimbatore (Report 2010). This incident highlighted the importance of analysing maggots to confirm poisoning as a cause of death when working with highly putrefied carcasses (see also Chapter 3, Section 3.7).

Malicious poisoning does not end with the target animal, but can also affect other wildlife via secondary poisoning. Scavengers and carrion-eaters like vultures (*Gyps* spp.), crows (*Corvus splendens*), black kites (*Milvus migrans*), Brahminy kites (*Haliastur indus*) and hyena (*Hyaena hyaena*) are the most common non-target species that bear the brunt of secondary poisoning. A recent news report by the Wildlife Trust of India (WTI) described the death of a number of Himalayan griffon vultures (*Gyps himalayensis*), slender-billed vultures (*G. tenuirostris*) and white-rumped vultures (*G. bengalensis*) due to secondary poisoning with unreported pesticides (WTI News Report 2009). In one incident, the vultures were killed after consuming the carcass of a dog poisoned by local people. The dog had killed a goat in the village and the family retaliated by lacing the goat carcass with a pesticide. Vultures then scavenged on the carcasses of both the dog and the goat. Twenty-one birds

died, while ten were rescued by the International Fund for Animal Welfare (IFAW)/Wildlife Trust of India run Centre for Wildlife Rehabilitation and Conservation (CWRC) in Sivasagar, Assam.

A similar incident was reported in the Mudumalai wildlife sanctuary in Nilgiri Biosphere Reserve (Report 2001). A hyena, several white-backed vultures and some crows were killed by secondary poisoning (though the poison itself was not identified).

There are also instances where large carnivores, which also scavenge, fall victim to secondary poisoning. Wild boars are the most common targets for primary poisoning. They are listed in Schedule III of the Wildlife Protection Act 1972, and a restriction imposed on hunting the species has led to an outburst in their population. They are found in large numbers in most forest habitats, and can cause extensive damage to crops such as banana, potato and carrot, which can all be planted in proximity to the forest. In retaliation, farmers often place poison or even explosives in bananas, potatoes or other edibles. The animals then succumb to poisoning (or starve, having had their jaws broken). A news magazine has reported that 'flour balls' (explosives wrapped in flour and connected to a crude detonator) are bitten by the boar, explode, and then cause severe damage to the jaw (Report 2002). Boars that die due to poisoning become a source of secondary poisoning for other scavengers, including large carnivores.

In January 2008, a male tiger was found dead (refer to Figure 4.5), along with three wild boar and a mongoose (a small carnivore, family *Herpestidae*) in a tea plantation in Devarshola, Nilgiris Biosphere Reserve (Kalaivanan, Venkataramanan, Sreekumar et al. 2010). The boar and mongoose stomachs contained plantain and banana tubers, while that of the tiger contained about five kilograms of undigested boar flesh. Circumstantial evidence (an empty cover for phorate 10% granules), was recovered adjacent to the boar carcasses. A composite sample (about 250 grams) containing stomach, intestinal loop with contents and portions of liver, tested positive for an OPC (phorate) by GC/MS. The sample was also tested for carbofuran, but none was detected. Evidence suggested that the boars had been baited with phorate-laced plantain and secondary poisoning of the tiger had occurred through ingestion of boar carcass(es). A similar incident occurred in June 2009 in Mudumalai Tiger Reserve, also in the Nilgiri Biosphere Reserve. Here, phorate was detected in wild boar flesh found in the stomach of a black panther (melanistic variant of *P. Pardus;* Kalaivanan, Venkataramanan, Sarkan et al. 2010).

Arora (2003) reviewed several cases of wildlife poisoning in India and the etiology of carbofuran was not implicated in any of them. Poisoning was due to chlorinated hydrocarbons in leopard, endosulfan and malathion in a tigress, HCN in another tiger and an elephant, aconite (a herbal poison) and endosulfan in rhinos, zinc phosphide in a lion and demecron in an elephant.

Arora (2008) has also described chlorinated hydrocarbon poisoning in three leopard cats (*Prionailurus bengalensis*) at the Zoological Gardens in Guwahati, Assam, as well as in 50 wild jackals (*Canis* sp.) in Lakhimpur, Uttar Pradesh. Also, zinc phosphide poisoning was reported in a tiger at Mysore Zoo, Karnataka and deaths of three elephants at Sonitpur, Assam due to malicious 'carbamate insecticide' poisoning.

A news report in the *Times of India* (dated 27 June 2007) reported that a leopard died from suspected poisoning in Mathipalayam near Coimbatore (Report 2007). A laced cow carcass was reportedly used as bait. In India, carnivores tend to be poisoned after preying on livestock, and the most common bait is via carcasses laced with poison. Elephants are poisoned via food items like bananas, electuaries (where the compound is mixed with a sweetener), pumpkins or arrack (a locally brewed alcohol), all of which they relish. Birds tend to be exposed to seeds laced with pesticides.

As noted from the previously discussed incidents, the mode of poisoning and the bait used tend to differ according to the species being targeted. The popularity of a compound as a poison among local people is a major factor in determining whether it is used for this purpose. In India, it seems that carbofuran is not as popular as some of the other compounds mentioned here (such as OPCs).

Figure 4.5 Male tiger found to have been poisoned by the organophosphorus compound phorate

Nevertheless, India cannot boast that it has fewer incidences of deliberate wildlife poisoning using carbofuran in relation to the rest of the world. Incidences could well be going unnoticed, unreported or uninvestigated. Likewise, pesticide poisoning may be misclassified since it can exhibit similarities (in terms of clinical signs) with a number of illnesses. As detailed here, incidents are also certainly being reported as 'poisoning by a pesticide' without further detailed investigation or specification of the pesticide(s) involved.

Even if incidences are confirmed, they are often improperly documented, and information can remain in the form of a postmortem report only (refer to our References section). Many reports are based on circumstantial evidence, and only a few are authenticated by chemical analysis. In India, the poisoning surveillance system with respect to wildlife is not well formed or coordinated. A veterinary toxicological service network (like the one recommended by Motas-Guzman, Marla-Mojica, Romero et al. (2003)) is required in order to document and mitigate incidences of poisoning. Where human instances of poisoning are concerned, there are four poison information centres in India, which are specialised units that provide information regarding the prevention and treatment of poisoning, as well as hazard management. As maintained throughout this book, without proper surveillance and an information system focused on wildlife poisoning, it is difficult to formulate effective policy changes on this issue.

4.10 Potential short and long-term solutions

The deleterious effects that arise following the use of carbofuran at approved levels will only be controlled by a reduction in the overall consumption of the pesticide within the country. Cotton and rice account for the major proportion of pesticide used in India (45 and 20%, respectively) even though they are cultivated in only 5% and 24% of the total cropping area. Other cereals/millets/oil seeds are cultivated in 58% of India's total cropping area, yet consume only 6–7% of the total pesticide used (Abhilash and Singh 2009). Crops which require extensive pesticide application should be brought under the Integrated Pest Control Programme (IPCP). This programme involves raising resistant crop varieties and integrating cultural and biological practices with minimal chemical pesticide use. For example, non-chemical management practices (provided by Pandey, Kalra and Gupta (2009)) to control nematodes could include: fallowing (where the land is not planted for a certain period of time), flooding, changing the sowing and/or planting time, crop rotation, the use of an antagonistic crop, the use of nematode-free planting material or seeds, summer ploughing/soil solarisation (to expose nematodes to solar radiation), organic amendment and biological control.

Earlier, we noted that carbofuran misuse arises through improper use of the compound by farmers (which results in them harming themselves), and through excessive applications. The occupational hazard associated with carbofuran could be avoided if the proper practice outlined for application of the pesticide was followed. Abhilash and Singh (2009) suggest several options, i.e., enhancing operator knowledge and providing properly designed equipment and protective wear. At the moment, farmers are more commonly concerned only with the potential for loss in crop yield. However, it is important that they are made aware of the deleterious effects of excessive pesticide use in order to protect their own health and that of the environment. An efficient monitoring system, which also acts to streamline the use of carbofuran, by highlighting safe practice and recommending effective doses, may help reduce accidents associated with misuse of the pesticide.

4.10.1 Alternatives to carbofuran

Carbofuran is widely used in India, especially to control plant pest species. Bearing in mind its potential to cause harmful effects in the environment (even when it is used in an approved manner, as discussed in Chapters 7 and 8), and its potential illegal abuse in terms of deliberate poisoning, several

alternatives are under trial. A few are commercially available. One is a bio-pesticide called 'Havana', which contains Azadirachtin at 0.15%, an extract from Indian neem (*Azhadiracta indica*). This has been recommended by the manufacturer for use in place of carbofuran as an insecticide/nematicide. However, it is much more expensive (130 rupees per kilogram or 3 USD per kilogram) when compared to carbofuran (65 to 80 rupees per kilogram or 1.5 to 2 USD per kilogram). Other compounds such as lantanoside, linaroside and camarinic acid, which are isolated from the aerial parts of *Lantana camara* (a flowering plant in the verbena family), were also tested for nematicidal activity against the root knot nematode (*Meloidogyne incognita*). They were found to be 90, 85 and 100% effective respectively at a 1.0% concentration (Begum, Wahab, Siddiqui et al. 2000). Such results are comparable to those obtained using Furadan (i.e., 100% mortality at a 1.0% concentration).

Experiments have also revealed that other bio-agents such as *Paecilomyces lilacinus* and *Trichoderma viride* (both naturally-occurring fungi), along with mustard oil cake, were effective in controlling root knot nematode to an extent comparable with Furadan (Goswami, Pandey, Ratour et al. 2006). Another bio-agent (and fungi) *Trichoderma harzianum*, was more effective than Furadan in controlling the root knot nematode in patchouli, an oil-yielding plant (Pandey, Kalra, Gupta et al. 2009). Certain products (Bionematon, Yorker, Trichostar, Tricho guard, Bioderma and Ecoderma) containing these bio-agents are now available on the Indian market for commercial use. Other promising bacterial biological agents with nematicidal activity are *Pseudomonas fluorescens* and *Pasteuria penetrans* (Khan 2008). However, farmers remain reluctant to switch to these alternatives, in particular because they find compounds such as carbofuran to be highly effective.

In Hawaii, experiments have been undertaken to control banana root borer (*Cosmopolites sordidus*) biologically, using predatory beetles (*Plaesius javanus* and *Dactylosternus hydrophiloides*). However, results were disappointing. Hence, Furadan is recommended as the only option for commercial farms there (Mau and Martin 2007). It is available only to licensed users, and no other alternative insecticide has been registered for use in Hawaii for this pest (Mau and Martin 2007).

As far as chemical pesticides are concerned, phorate is the nearest substitute available for carbofuran. Both are available in granular form, and they are often used in combination. They are both referred to as 'kurunai' (meaning granules) by local farmers in the Nilgiris District of Tamil Nadu. Phorate is available in a 10% (10 G) composition, and was more effective in controlling cut worm attacks on *Paulownia fortune* plants when compared to Furadan (Singh and Kumar 2006). However, phorate is even more harmful and is classified as 'Extremely Hazardous' while carbofuran comes under the 'Highly Hazardous' category as per the 2004 World Health Organisation (WHO) recommendations. Moreover, phorate formulations have been linked with several cases of intentional poisoning in India (refer to Table 4.7). Thus, in our opinion, phorate probably currently poses a greater problem than carbofuran in India.

4.10.2 Should carbofuran be banned in India?

Given the extent to which carbofuran is currently used as a nematicide/insecticide in India, there is trepidation with regard to banning it here. Crop varieties that offer the highest yield (which are required to meet the increasing demand for food within India) cannot be cultivated without the use of potent pesticides since their resistance to pests has now been lowered. While alternatives to carbofuran are under trial, and a few products have been introduced onto the market, farmers remain unconvinced that these offer effective and economical pest control. Farmers will never shift to biopesticides as long as carbofuran is available (especially at a lower cost), or until they are convinced that the substitute performs better than carbofuran. At this point in time, chemical equivalents to carbofuran are not available. Substitutes like phorate are even more hazardous and should perhaps be banned before carbofuran. Nevertheless, the harmful effects of carbofuran, not only as a poison but

as an unacceptable dietary risk (as a residue in food and water), especially to children, have to be kept in mind. Some of the results regarding bio-pesticides/fertilisers like azadirachtin (and other fungal agents) are encouraging, but large-scale testing has to be undertaken before such agents can be declared effective substitutes.

Banning carbofuran will not provide a complete solution either. For example, India has banned the use of the anti-inflammatory drug diclofenac (for veterinary use) in order to protect critically endangered *Gyps* vultures (see Oaks, Gilbert, Virani et al. 2004). However, even after the ban, the medicine remains available, and human preparations remain in use (Cuthbert, Green, Ranade et al. 2006). A similar situation has been reported for strychnine (Martinez-Haro, Mateo, Guitart et al. 2007). Widely used to poison predators in Spain, it was banned in 1994, but it is still used in deliberate wildlife poisoning (see also Section 5.5). The source of strychnine used today is unclear, but chemists, veterinarians or existing stocks are all potential sources (Martinez-Haro, Mateo, Guitart et al. 2007).

This chapter has outlined a number of poisoning incidents in India. Data demonstrate that carbofuran is only one of several compounds commonly used in malicious wildlife poisoning. If carbofuran were banned, farmers would simply use other toxic compounds. Thus, the most effective way to stop deliberate poisoning is to mitigate the human-wildlife conflict that drives it.

4.11 Mitigation of human-wildlife conflicts

4.11.1 Habitat conservation

At the root of human-wildlife conflicts in India is the loss and fragmentation of wildlife habitat (see Figure 4.6). Efforts are underway to increase the land area designated as Protected and fill the gaps within habitats. A report by the Wildlife Institute of India proposes to increase the present cover designated as Protected, from 4.70 to 5.74%. Fewer gaps in the pattern of coverage are also suggested, i.e., larger individual land parcels with more interconnection between them (Rodgers, Panwar and Mathur 2002). Integrated management of Protected Areas with surrounding 'managed forests' is also essential. Efforts are currently being made to bridge gaps within certain Protected Areas and the areas around them. One good example is given by the Terai Arc Landscape programme (launched in 2001 by the World Wildlife Fund (WWF) and the Indian and Nepalese Government). Wildlife conservation organisations, including Save the Tiger, aim to unite 11 existing reserves into one functioning ecosystem. Under the programme, local people are given incentives to plant trees or tall thatch grass. Tigers can then use the grass as cover and people can harvest the excess grass.

Similarly, Project Elephant is providing funding to restore lost corridors for elephants and make easy their movement between habitats. In a December 2008 press release (from the Ministry of Environment and Forests, Government of India) Project Tiger enhanced its funding for village relocation/rehabilitation for people living in core or critical tiger habitats from rupees one lakh per family (approximately 2 250 USD) to rupees ten lakhs per family in order to arrest habitat fragmentation. Given the current economic climate, this increase appears to be justified and sufficient.

This will be a challenging process (i.e., to patch the holes that now exist in India's wildlife habitat) since human relocation involves issues of ownership, feasibility and cost. Forcing people from their home and land will quite potentially create a negative attitude towards wildlife. The process is sensitive and has to be handled delicately, and it may take many years to restore any single area. But, of all the solutions available, human relocation and habitat restoration for wildlife will hopefully provide a permanent solution to conflict. The Wildlife Trust of India conducted an excellent survey to identify elephant corridors throughout India and has described the status of each in terms of human settlement (Menon, Kumar, Tiwari et al. 2005). Such information will be useful when formulating policy aimed at restoring these important corridors for pachyderms.

Figure 4.6 Loss and fragmentation of viable habitat is at the root of human-wildlife conflicts in India

4.11.2 Community-based solutions

Solutions to human-wildlife conflict must be community-based and include the people involved in such conflicts since they will also be affected by the proposed solution. No amount of legislation or prevention by force can mitigate these conflicts. Such legal action could in fact harm conservation by creating negative attitudes. Ward (1994) has described how community participation and the introduction of modern agricultural practices, organised through the Ranthambhore Foundation, helped prevent forest exploitation. Practices/facilities introduced included: irrigation facilities, the rearing of high yielding Jersey and Friesian cattle, bio-gas production, the formation of a dairy cooperative, and the formation of village forest protection societies.

Pepal and Khanal (1992) have also described a similar community-based conservation programme for two contiguous parks, i.e., the Mount Everest Park in Nepal and the Oornolangma Nature Reserve in China. The proposed project focused on the introduction of higher milk-producing animals, the education of local people, the promotion of women's welfare, and community participation in park maintenance. This is a model for how conservation and the protection of natural resources can coexist with local economic development. Other programmes involving community participation (for example, to conserve the tiger habitat at Simlipal Tiger Reserve), have been funded by the Save the Tiger Fund (Report 2004).

4.11.3 Compensation for loss of property

Loss of life and property is another factor which triggers conflict between wildlife and affected people. Losses (as described earlier) in the form of human life, livestock, via crop raiding, or by injury due to attack and damage to property all occur. Compensation for such loss is a primary objective for most of the government and non-government organisations involved in mitigating such conflict. The availability of funds, accurate loss estimation, beneficiary identification, false claiming, delay, and inadequate payment, are just some of the constraints encountered when executing such compensation schemes. The hardship people have to undergo to receive this often meagre compensation further aggravates any negative attitudes towards wildlife.

By registering livestock maintained in the fringe of forest/Protected Area, the compensation process may be made simpler and more rapid. For example, one such programme, funded by the Hill Area Development Programme, is functioning through the Department of Animal Husbandry in the Nilgiris District of India. Innovative compensation schemes regarding crop and livestock insurance could also help (Madhusudhan 2003). Toda buffaloes are semi-wild animals maintained by the Toda Tribal people in the Nilgiri Hills of Tamil Nadu (primarily for their milk). The tribes consider predation by wild carnivores, particularly by tiger and leopard, to be a major threat to their animals. The Wildlife Trust of India has proposed a project whereby compensation is gained through the replacement of the Toda buffalo lost, rather than through money. In general, the Toda are pure vegetarians, and have a friendly attitude towards the forest. In order to stop them developing a negative attitude towards carnivores, the project proposes to maintain a herd of Toda buffalo (and therefore any animal killed by predation in a village will be replaced from this herd).

Human-wildlife conflict can be averted well in advance if wild animals are prevented from straying into human settlement. Powered fencing, while expensive, is a very efficient way of keeping wild herbivores off cultivated land. Another way to avoid crop damage is to change the cropping season, or cultivate cash crops which are not palatable to wildlife. For example, certain medicinal plants can be grown in a limited area, which are not favoured by wildlife but can provide comparable income for the farmer (Rao, Maikhuri, Nautiyal et al. 2002). Native practices such as sprinkling Gullal (red colouring powder) along a farm's boundary, burning human hair (Kholkute 2004), or spraying

'rotten egg solution' (prepared by mixing two rotten eggs in ten litres of water) over crops (as per Report 2009d) can also be used.

Predation of livestock by wild carnivores can be prevented by making natural prey more abundant/ easier to find than the livestock. By maintaining forest habitats suitable for herbivores, a good prey base is sustained. The Nilgiri Hills in the Western Ghats were once a shola-grassland ecosystem, a unique type of forest containing a high biodiversity of flora and fauna and having high water retention properties. Now, the region has lost most of its grassland to eucalyptus, pine and tea plantations. This has resulted in a reduction in the wild herbivore food base, forcing carnivores to look for alternative prey such as livestock. Similarly, the replacement of grass in the undergrowth of tropical forests with weeds like *Lantana americana* has resulted in a fodder shortage for herbivores. This is compounded by the presence of numerous head of unproductive low-milk producing cattle on the forest fringe. These then compete with the wild herbivores for the already declining fodder (see Figure 4.7). Replacing such cattle with fewer/ higher yielding animals is another option.

Finally, the concept of 'conditioned taste aversion' (CTA), where carcasses are laced with chemicals which stimulate a sense of aversion after consumption to dissuade predators (Given 2007), could be popularised among farmers. Similarly, by incorporating repellents in carbofuran formulations, predators could be discouraged from consuming pesticide-laced baits (Martinez-Haro 2008). Repellents could enable wild animals to sense the presence of carbofuran in a bait and thus dissuade them from consuming it. The use of chemical repellents to minimise seed consumption by and mortality of wildlife in agricultural areas is the subject of Chapter 7.

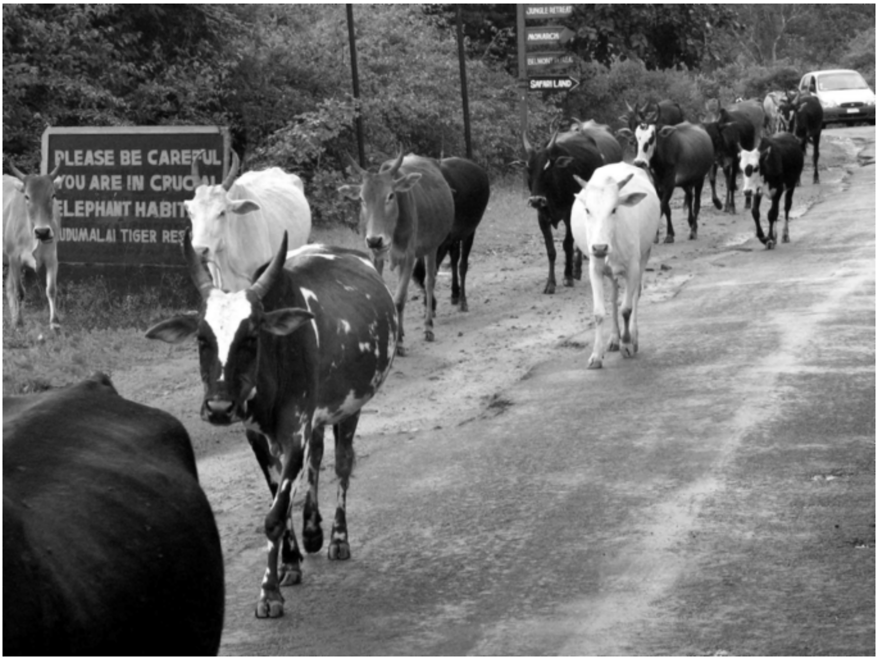

Figure 4.7 Low-milk producing cattle kept on the forest fringes compete with wild herbivores for food resources

4.12 Conclusion

India, with its unique wildlife diversity and large human population, faces several types of human–wildlife conflict. Such conflict is inevitable due to a burgeoning human population and an increasingly fragmented wildlife habitat. India has 2% of the world's landmass (living surface) but supports 15% of the human population and 16% of its livestock (Sinha 2002). The impact of human population growth on the loss of wildlife habitat in nine countries (including India) was reported at the 1990 Perth Conference of the IUCN (Kim 1991). It was estimated that 80% of wildlife habitat in India has now been lost.

As a basically agrarian society, a dependence on pesticides for optimal crop production becomes inevitable. Carbofuran (as 3% granules) is readily available without any imposed restrictions. To our knowledge, although many substitutes are under trial, none currently appear to be as attractive to farmers. Furthermore, carbofuran is also only one of a number of pesticides now being used to illegally poison wildlife. Any ban or restriction on its use must take into account the benefits of carbofuran in farming as well as its potential to be abused for poisoning. Until a suitable 'wildlife-safe' replacement is available for carbofuran, the following suggestions could go a long way toward reducing the number of incidents relating to its illegal use.

- Address human-wildlife conflict by:

  1. *Reducing animal incursions into human habitation* by effective and user-friendly methods (i.e., power fencing, use of rotten egg solution, use of conditioned taste aversion techniques, etc.).
  2. *Encouraging active community participation* by those living in fringe areas of protected habitat. Inducing a sense of 'belonging' among people towards wildlife.
  3. *Providing speedy, sufficient and hassle-free relief* to those affected by conflict-in turn this will reduce negative attitudes toward wildlife. Presently, a farmer who loses a head of livestock to a wild carnivore has to make numerous trips to an office situated in a city for meagre compensation. This dissuades people from pressing for compensation, and may force them to take matters into their own hands.
  4. *Removing problem animals* like marauding elephants and carnivores (where predation or man eating occurs) and rehabilitating them in places like zoological parks.
  5. *Regulating the distribution and use of carbofuran by:*

     I. Educating farmers about the benefits of its safe and proper use, as well as the adverse effects to humans and the local environment by misuse and abuse.

     II. Improving the implementation of existing regulations which monitor the sale and use of carbofuran and also the type of guidance given by stockists and retailers who sell it.

     III. Incorporating repellents in carbofuran formulations to dissuade its consumption in laced carcasses used to kill wildlife.
  6. *Strengthening the surveillance system by:*

     I. Training veterinarians, forest personnel and NGOs on standard procedures involved in handling cases of poisoning.

     II. Setting up poison information centres, which deal with issues related to wildlife poisoning.

III. Encouraging prompt, accurate and detailed documentation of wildlife poisoning to generate baseline data.

Any step in the direction of conflict alleviation must take into consideration the plight and concerns of the local people. After all, it is they who are most likely to be affected, and they who will ensure that solutions are both practical and permanent.

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5 Regulation of carbofuran and its use to poison wildlife in the European Union and the rest of Europe

5.1 Introduction

The European Union (EU) was officially established with the signing of the Maastricht Treaty, which came into force 1 November 1993 (http://europa.eu/legislation_summaries/economic_and_monetary_affairs/institutional_and_economic_framework/treaties_maastricht_en.htm). The EU currently comprises 27 Member States. Iceland, Croatia, Turkey and Macedonia are presently considered 'Candidate' countries, whereas Albania, Bosnia and Herzegovina, Montenegro, Serbia and Kosovo are considered 'Potential Candidate' countries (http://europa.eu/about-eu/member-countries/index_en.htm and see Figure 5.1).

Carbofuran was authorised individually by many, but not all, countries within the EU/Europe (see Table 5.1). On 13 June 2007, the Commission of European Communities (CEC) issued Directive 2007/416/EC 'concerning the non-inclusion of carbofuran in Annex I to Council Directive 91/414/EEC and the withdrawal of authorizations for plant protection products containing that substance' (http://eur-ex.europa.eu/LexUriServ/site/en/oj/2007/l_156/l_15620070616en00300031.pdf; CEC 2007). At this time, the effects on both human health and the environment were assessed according to the provisions outlined in EC Regulations 451/2000 and 703/2001, both essentially concerned with establishing a list of active substances to be assessed for inclusion (or exclusion) in Annex I to Directive 91/414/EEC. A risk assessment report on the 'active substance carbofuran' (i.e., active ingredient) was peer-reviewed by the relevant Member States and the European Food Safety Authority (EFSA) within its Working Group Evaluation and their conclusions were presented to the Commission on 28 July 2006. Provision (5) of the 2007 Directive stated that:

> During the evaluation of this active substance, a number of concerns have been identified. The risk assessment for ground water contamination could not be concluded, in particular because the data supplied by the notifier within the legal deadlines did not provide sufficient information about a number of metabolites which

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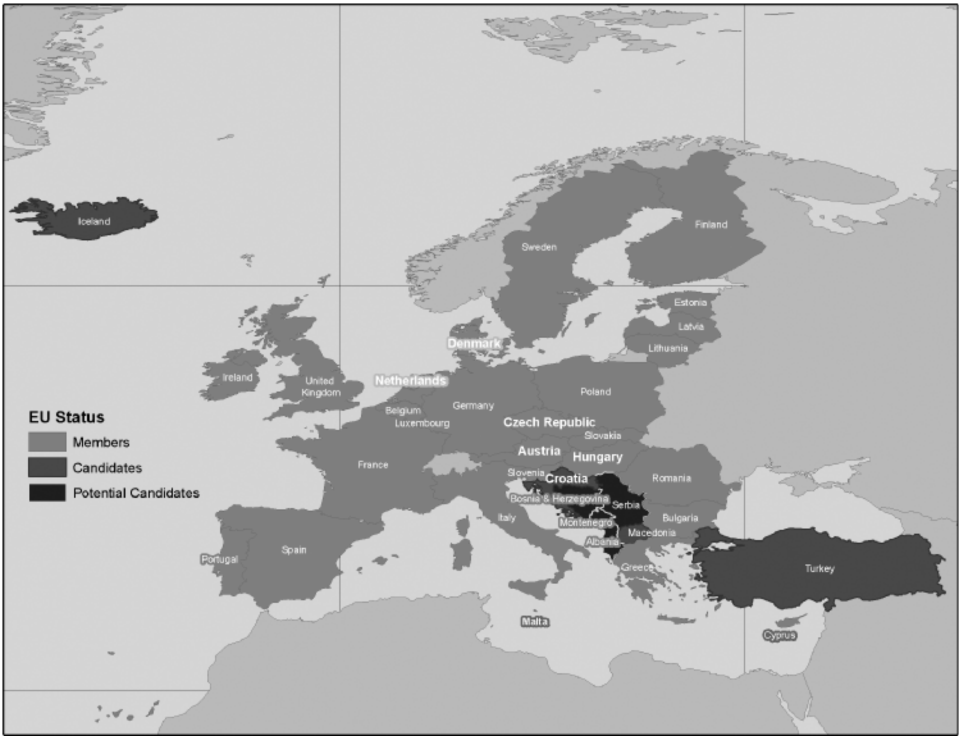

Figure 5.1 Countries of the European Union (EU) and Europe (as of April 2011), prepared by John C. Nelson and Wayne E. Thogmartin, United States Geological Survey, Upper Midwest Environmental Sciences Center)

> have a hazardous profile. Also the consumer risk assessment, which raised a concern about the acute exposure of vulnerable groups of consumers, in particular children, could not be finalised due to the lack of information as regards certain relevant residues. Furthermore, the data supplied by the notifier within the legal deadlines was insufficient to allow the EFSA to access the ecotoxicological effects of the active substance. As a result, concerns remain as regards risk assessment for birds and mammals, aquatic organisms, bees, non-target arthropods, earthworms, and soil non-target organisms. Consequently, it was not possible to conclude on the basis of the information available that carbofuran met the criteria for inclusion in Annex I to Directive 91/414/EEC.

Provision (6) further stated that: 'Despite the arguments put forward by the notifier [in this case FMC], the concerns identified could not be eliminated'. Therefore, authorisations for plant protection products containing carbofuran were revoked, and such products were to be withdrawn from the market by 13 December 2007. Member States were granted a grace period for phaseout, during which remaining stocks would be used up, which expired on 13 December 2008. However, as of April 2011, carbofuran products are still registered for use in some Member States/European countries, for example in Switzerland, where the use of carbofuran products (which, it must be

Table 5.1 Registration periods of carbofuran products in selected countries of the European Union and the rest of Europe

Country	First date of registration	Last date of registration	Source
Austria	unknown	13/12/2007	See Section 5.4
Belgium	01/10/1975	13/12/2007	Santé publique, Sécurité de la Chaîne alimentaire et Environnement www.health.fgov.be
Croatia	unknown	13/12/2007	See Section 5.7
Czech Republic[a]	1972	13/12/2007	State Phytosanitary Administration of the Czech Republic www.src.cz
Germany	1972[b]	2005	Federal Office of Consumer Protection and Food Safety (BVL) Department of Plant Protection Products
Hungary	1973	13/12/2007	Central Agricultural Office of Hungary
Malta	01/12/2005	13/12/2007	Regulatory Affairs Directorate, Foodstuffs, Chemicals, Pesticides and Cosmetics Unit, Malta Standards Authority www.msa.org.mt
Netherlands[a]	30/09/1994	13/12/2007	Board for the authorisation of plant protection products and biocides www.ctgb.nl
Portugal	19/06/1981	13/12/2007	DSPFSV/Divisão de Homologação e de Avaliação Toxicológica,Ecotoxicológica, Ambiental e da Identidade de Produtos Fitofarmacêuticos www.dgadr.pt
Sweden	20/01/1999	31/12/2005	Pesticides and Biotechnical Products Division, Swedish Chemicals Agency (KemI) www.kemikalieinspektionen.se
Switzerland	Ca. 1973	Still registered for some uses, as plant protection product	Federal Office of Public Health, Division of Chemical Products www.blw.admin.ch

[a]Five carbofuran products registered for use at different times, all Furadan formulations, more information available from editor upon request.
[b]Before 1968, an authorisation was not compulsory for the marketing and use of plant protection products and it is therefore possible that such products may have been on the German market before the first authorisation was granted in 1972.

noted, was allowed for scientific purposes) will come under new review in 2011, and a decision is expected to be made within the year (Swiss Federal Office for Agriculture, personal communication, 2011).

In this context, 'revocation' refers to loss of approval of the sale, supply and advertising of a product, 'expiration/expiry' is the date on which an approval ends, and 'withdrawal' refers to the removal of an approved product from the market, mostly (but not always) by the approval holders themselves (UK Chemicals Regulation Directorate, personal communication, 2011). After a revocation has been issued and the grace period has elapsed, the fate of the remaining stocks of carbofuran products becomes ambiguous. The allocated grace period and management of remaining carbofuran products varies between EU Member States/European countries. In Sweden, for example,

a total grace period of two years is issued, providing one year for retailers to empty their stocks, and another for end-users to finish their supplies (Swedish Chemicals Agency, personal communication, 2011). In some cases, in the interests of 'good customer relations and stewardship', manufacturers will take back remaining stocks of their product. In other places (i.e., the Republic of Ireland, see Chapter 6) the product must be disposed of as hazardous waste at the expense of the owner.

Elsewhere e.g., Malta, if prohibited compounds are not used up by the grace period, the local importer and the authorisation holder discuss between them what decision to take, whether to destroy the products (as hazardous waste) or return them to the authorisation holder who may then opt to export them to countries outside the EU (Foodstuffs, Chemicals, Cosmetics and Pesticides Unit (Malta), personal communication, 2011). As such, the Regulatory Affairs Directory there leaves this decision to the importer/authorisation holder, because their responsibility is to ensure that prohibited products are not placed on the market (although their responsibility does extend to ensuring that prohibited products are disposed of appropriately).

All such discrepancies will be regulated under the new Pesticide Regulation 1107/2009, which enters into force 14 June 2011 and replaces Council Directive 91/414/EEC. Article 20.2 (Renewal Regulation) stipulates that, if approval of an active substance is not renewed:

> Where the reasons for not renewing the approval do not concern the protection of health or the environment, the Regulation referred to in paragraph 1 shall provide for *a grace period not exceeding six months for the sale and distribution, and in addition a maximum of one year for the disposal, storage, and use of existing stocks of the plant protection products concerned. The grace period for the sale and distribution shall take into account the normal period of use of the plant protection product but the total grace period shall not exceed 18 months.* In the case of a withdrawal of the approval or if the approval is not renewed because of the immediate concerns for human health or animal health or the environment, the plant protection products concerned shall be withdrawn from the market immediately.

Regulation 1107/2009 is particularly timely, given that despite Directive 2007/416/EC (regarding the ban), carbofuran-related wildlife mortality continues to be reported throughout the EU and the rest of Europe. In this chapter, accounts of such incidents are provided from the Czech Republic, the Netherlands, Austria, Spain, Hungary and Croatia. They reveal a cross-section of social, economic and geopolitical conditions which have all contributed to the extent of the use of carbofuran to poison wildlife. Indirectly, they also illustrate how the discrepancy between registration periods and revocations throughout Europe (see Table 5.1) has nourished illegal stockpiles of the product. Finally, these accounts also very effectively convey that local wildlife poisonings are undermining national conservation initiatives, that continued monitoring and vigilance is required, and that the enaction of stringent legal procedures and penalties is essential.

5.2 Intentional poisoning of piscivorous species and other wildlife with carbofuran in the Czech Republic

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5.2.1 Introduction

In the Czech Republic, there is a longstanding tradition of raising fish in artificial water bodies. Indeed, our first fishponds were built in the thirteenth century. Fish was an important component of the traditional Catholic practice of fasting on Fridays and common carp (*Cyprinus carpio*) remains the traditional Christmas meal for the vast majority of Czech families. Thus, producing fish in fishponds has been a good source of income for a lot of farmers. Many wetlands have been converted to fishponds over the last 150 years, allowing the owner to profit economically from what is considered otherwise unusable land. Recent estimates indicate that over 20 000 tons of fish (mostly carp) are produced in more than 50 000 fishponds across the Czech Republic (Ženíšková and Gall 2009). These ponds vary significantly in size, ranging from less than 0.1 to several hundreds of hectares. They are scattered throughout the landscape and in many cases organised in cascades of ponds which create clusters of water bodies.

Many of the fishponds were established several decades or centuries ago and, as such, usually possess natural, stable banks which provide excellent habitat for species other than fish. Fishponds therefore provide suitable, much-needed habitats in the country, where large scale transformation of natural wetlands for agricultural and forestry purposes have occurred, particularly in the last century. In fact, the presence of the fishponds is the main reason that many populations of wildlife species live and survive along the water bodies and wetlands at all, and many are considered to be biodiversity hotspots and are even protected by the State.

Political changes occurring in the country in 1989 (i.e., the anti-Communist revolution) had, and still have, far-reaching social, economic and environmental consequences. These changes also led to modifications in the ownership structure and hence in the whole economy of the country. In the 1950s, the private property of many citizens was nationalised by the leading Communist party because private businesses were not allowed. During the 1990s, many State-owned companies were given back either to former owners or their descendents, or they were privatised. Major changes have also occurred in the transfer of ownership of land, which includes fishponds.

Apart from such significant changes to the economy of the country, the democratic development of the State-led to an increased awareness of environmental issues in our people. Dramatic decreases in air and water pollution, for example, have been recorded, and as a consequence of better environmental quality and strict species protection, populations of many once critically endangered species are now recovering. An increase in the population of several fish eating (or piscivorous) species in the last two decades, namely cormorants (*Phalarcrocorax carbo*) and otters (*Lutra lutra*) among others, together with change of ownership of fish farming enterprises (from public to private) put special pressure on the conflict between humans and wildlife. On the one hand, there is generally high interest in the conservation of species and habitat, but on the other hand, the right of citizens to use their land and reduce losses caused by wildlife is also considered very important. In the Czech Republic, the fish farmer and the species which eat his fish (e.g., otter, cormorant and heron (*Ardea cinerea*)) have a long-standing relationship. Piscivorous species are not welcome at fish ponds and thus measures have been taken to remove them. Before, unwanted predators were most often trapped or shot, but as piscivorous predators are protected nowadays, methods that are secretive and harder to detect, for example poisoning, are coming into use.

5.2.2 Poisoning of wildlife by carbofuran and its detection within the Czech Republic

All insecticides containing carbofuran were sold in the Czech Republic under the trade name Furadan. The form of insecticide varied from granules (25 kg per piece) to suspension (18 litres). Following the producer's instruction manual for treatment of one hectare of field, approximately 6 litres of Furadan

350 F was used (www.agromanual.cz/download/pdf_bezpecnost/bl_furadan_350_f.pdf). One litre of Furadan 350F contains about 375 grams of carbofuran as an active ingredient. LD_{50} values of 2 and 19 mg/kg have been reported for mice and dogs, respectively (Cornell University 1993, and refer to Chapter 2). Taking into account the average size of an adult otter (6 kg) and using a 'best case scenario of lethality' (i.e., the higher lethal dose of 19 mg/kg), one litre of Furadan 350F in theory contains enough carbofuran to kill more than 2 500 otters, a figure that exceeds the whole population of the species within the country (Poledník et al. 2007). We obtained this mortality estimate as follows:

1. Multiplying the LD_{50} of 19 mg/kg by the average weight of the otter, 6 g, which gives a result of 0.132 g. We use this value to represent the amount required to kill one otter.
2. Dividing the amount of (carbofuran) active ingredient in 1 litre of Furadan 350F, 375 g, by the number of grams of active ingredient required to kill one otter, 0.132 g, which gives a value of 2 840 otters.

Here, we report on poisoning of otters and other piscivorous species based on our experience within two nature conservation and monitoring entities. The Agency for Nature Conservation and Landscape Protection of the Czech Republic (Czech acronym: AOPK CR) is a governmental body that was established in 1995 by the Ministry of the Environment. Its primary aim is to protect the nature and landscapes of the Czech Republic. To do this, AOPK CR monitors trends in selected habitats and populations of endangered and/or specially protected wildlife species and provides technical and expert support. It also implements practical measures to conserve nature and landscapes within the 24 Protected Landscape Areas and the 208 National Nature Reserves and National Nature Monuments in the Czech Republic. Other activities include administering national subsidy programmes and some European Community funds intended for nature and landscape conservation, payment of financial compensation for damages caused by specially protected animals and for loss of property to agriculture, forestry and fishpond management. Finally, AOPK participates in international nature conservation and landscape protection efforts and is a Scientific Authority of the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES) in the Czech Republic.

ALKA Wildlife is a nongovernmental, nonprofit organisation that was established in 2007. It focuses primarily on applied ecological research of various mammalian and bird species. Despite its short history, it has achieved an important position as a partner for State nature conservation authorities. The ALKA team has significantly contributed to the Eurasian otter management plan proposal for the Czech Republic and in cooperation with AOPK CR, it is responsible for designing and carrying out the monitoring of otters. Moreover the team is coordinating nationwide monitoring of the saker and peregrine falcons (*Falco cherrug* and *Falco peregrinus*, respectively). The scope of the team extends far beyond these three species and ALKA is involved in the research and conservation/monitoring of other species such as wildcat (*Felis silvestris*), European mink (*Mustela lutreola*) and American mink (*Neovison vison*).

Several substances have recently been recorded in connection with wildlife poisoning in the Czech Republic: carbofuran, strychnine, methomyl and the anticoagulant agent warfarin. Of these, carbofuran has been used most often in the last years, however, since its use is now prohibited, methomyl (which is not restricted) has also been used. These compounds are used to lace different types of baits such as fish, eggs, meat and remains of small game species. Depending on the bait used and where it is placed (e.g., at the water's edge, at feeding sites, near houses with domestic animals) different species are affected, including birds of prey (most commonly *Buteo buteo, Milvus sp. Circus sp., Haliaeetus albicilla*), carnivores (*Vulpes vulpes, Lutra lutra, Martes foina*) and the occasional scavenger (Corvidae).

Most of the wildlife poisoning cases are proven by analysis of the stomach content and liver, by gas chromatography (with use of nitrogen-phosphor detector, NPD) at our State Veterinary Institute.

Analysis of a single sample costs 900 Czech koruny (CZK, equivalent to approximately 50 USD) and the results are reported in milligram of carbofuran (or other compound), per kilogram of sample. Analysis is paid by private donations, for example citizens who find poisoned wildlife and wish to know the cause of death, by NGOs or by AOPK CR since no special State funding is available.

Since 2005, 14 Eurasian otter (*Lutra lutra*) poisonings with carbofuran have come to light, from six separate cases (Poledníková et al. 2010). The fact that these cases were located in quite different parts of the Czech Republic suggests that poisoning of this species with carbofuran is a widespread rather than regional practice. Although otters are present at fishponds year-round, the poisonings occurred in either winter or spring, when otter food sources are limited. Since the otter does not commonly scavenge dead prey, and where only dead fish is used as bait, we expect that the effect of these recent poisonings on the otter population is relatively low compared with other sources of mortality. However, as tends to be the case in such incidents, we also suspect that the actual number of otters being poisoned is much higher than we have reported. The recent population size of otters is estimated to be about 2 300 adult animals and the range of the species within the country is increasing (Poledník et al. 2007). Current models of population trend development suggest that otters can cope with only limited increase in their mortality rate and an annual rise of 100 dead animals per year (i.e., less then 5% of the adult population) would greatly heighten the risk of population extinction (Poledníková et al. 2010, unpublished data).

Another piscivorous species poisoned by carbofuran in the Czech Republic is the white tailed eagle (*Haliaeetus albicilla*). This is the largest eagle species in the country, frequently occurring in the vicinity of large water bodies and feeding mainly on fish and waterfowl, and often on scavenging carrion. The species was extirpated from the State territory of the Czech Republic in the middle of the nineteenth century and the first recent breeding of the species in the country was recorded in 1986. Since that time, the population is slowly increasing. In 2000, approximately 25 breeding pairs were recorded, increasing steadily to 61 then 87 pairs in 2009 and 2010, respectively (Šťastný et al. 2006; Bělka and Horal 2009; Bělka and Horal 2010). Breeding eagles and individuals overwintering from northern countries are also found here. Because it is a large bird and its presence along water bodies is evident, it rarely goes unnoticed by fishermen. This, and the fact that the species often scavenges dead animals along the water bodies makes it very sensitive to poisoning. Since 2006, up to ten individuals poisoned by carbofuran have been recorded annually. The recent population sizes reported for the species within the Czech Republic demonstrate that carbofuran poisoning has significantly affected the eagle population in the country and can influence populations in other countries as well.

5.2.3 Legal and institutional framework against wildlife poisoning in the Czech Republic

As a Member State of the European Union, the Czech Republic's entire legislative framework is in conformity with EU legislation. All substances containing carbofuran were banned in the Czech Republic in 2008 following the EU Commission Decision of 13 June 2007 (refer back to Section 5.1). The process of forbidding and withdrawing a substance can take time, during which there may be ample opportunity to accumulate supplies for future use. Consequently, the information that the use of carbofuran would soon be banned in the Czech Republic was withheld from the public. Other provisions are in place as well. According to the Game Management Act (No 449/2001) and Act No 246/1992 Against Cruelty to Animals, the placement of poisoned baits is strictly prohibited. Moreover most piscivorous species of the Czech Republic are strictly protected species and deliberate killing of any wildlife species is forbidden by the Nature Protection Act (No 144/1992).

Suspected wildlife poisoning should be reported to the police, since poisoning is considered a crime delict (i.e., anyone discovered to have known about such a crime but not reported it can be penalised). Unfortunately, up to now, police investigations have not identified any culprits. Various

NGOs concerned with environmental protection have criticised the police, saying that their investigations are very lax and generally show little interest in apprehending the perpetrator(s). This is partly because the police will not investigate a case before laboratory analysis has been conducted (usually by the State Veterinary Institute) and the use of poison has been established. This delays investigations and private citizens or organisations must pay for analyses in order to move the process forward. Imprisonment for one, two or even five years, a ban on professional activities or a financial penalty are the most serious legislative consequences in connection with the Czech Criminal Code. When a company is suspected to have breached the law, an 'entrepreneur' (i.e., acting on behalf of a business) can be fined an amount not exceeding 1 000 000 CZK (in excess of 50 000 USD, under the Chemical Substances and Preparations Act). A 'non-entrepreneur' (i.e., a person whose activities are for personal rather than commercial use) can be fined a value not exceeding 500 000 CZK (in excess of 25 000 USD, under the Plant Medical Care Act).

In this country, birds of prey are the most common victims of wildlife poisoning and as a result the Czech Ornithological Society (COS) is the leading organisation that deals with the issue of carbofuran poisoning. Since 2006, the organisation has developed a central database for registering the poisoning of animals by carbofuran (see www.karbofuran.cz). COS often pays for laboratory analysis of samples and offer on their website a reward for any person who gives information leading to the capture of those who poison wildlife. Every documented case of poisoning is divulged through the COS website, in newspapers and on television, with the aim of raising the awareness of the general public regarding poisoning of wildlife and discouraging such behaviour. COS also joined forces with the Czech and Moravian Hunting Association and prepared a leaflet about poisoning of wildlife (go to: www.karbofuran.cz/misc/Smrt_po_kapkach.pdf).

The Ministry of Environment of the Czech Republic recently acknowledged the problem of wildlife poisoning and, in 2010, initiated a meeting with responsible partners from the Ministry of Agriculture, the Ministry of Internal Affairs and various NGOs to coordinate and improve activities that prevent the poisoning of wildlife. With specific regards to the use of carbofuran as a poison, we think this is a very good thing, because the ban was quite recent and, before its implementation, carbofuran products were freely available to the general public and widely used in agriculture. Given the possibility that an unknown quantity of stockpiles of carbofuran products remain in the Czech Republic and that knowledge of carbofuran as a relatively easy way to dispose of 'nuisance' animals from fishponds has spread among fishermen, we cannot exclude a possible outbreak in its use as a poison wildlife in the country in the coming years.

5.3 Persecution and poisoning of birds of prey in the Netherlands

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5.3.1 Introduction

Although strictly forbidden by law (i.e., on flora and fauna, animal welfare and crop protection/biocides), persecution of wildlife remains a common practice in the Netherlands (i.e., Holland). Unfortunately, legal enforcement of wildlife issues is very poor here, which makes it difficult to find and pursue the culprit(s). As a result, we lack accurate data regarding the frequencies, locations,

identities, methods, and number of successful prosecutions. Even when an incidence of mass mortality arises and poisoning is suspected, only a fraction of the carcasses are submitted for analysis, which means that the number of casualties attributed to poisoning is underestimated. And, as stated elsewhere in this chapter, what we detect undoubtedly represents only a fraction of what is really occurring.

Persecution is frequently aimed at foxes (*Vulpes vulpes*), common buzzards (*Buteo buteo*) and goshawks (Accipiter sp.), all predators of small game, racing pigeons or livestock. However, since 2004, we have observed a disturbing trend whereby predators are persecuted by individuals who mistakenly believe that they are responsible for the decline in populations of meadow-dwelling birds (e.g., lapwings (*V. vanellus*) and black-tailed godwits (*L. limosa*)). Nest disturbance and destruction of nest contents, shooting, poisoning and trapping (cage and foot-hold) are among the methods used against predators. In reality, the meadow-dwelling species are not faring well because of intensification in agricultural practices, which forces the predators and meadow-dwelling species to be in closer confines (Teunissen, Schekkerman and Willems 2006).

The persecution is not carried out on an altruistic basis either, for the simple good of these species. Indeed, there is a tradition in the Province of Friesland (in the northern part of the Netherlands) to collect the eggs of lapwings and, because it is a 'tradition', EU permits have been issued, so that under certain regulations egg collecting is allowed by law. Since the dramatic reduction of meadow birds that has followed the agricultural intensification, the Dutch Ministry has been providing subsidies to farmers to promote agricultural practices that are favourable to the species, including a 'bonus' for each successful nest, which has unintentionally provided a financial incentive to persecute predators.

5.3.2 The scale of carbofuran use to poison wildlife, especially birds of prey, in the Netherlands

Poisoning is, in our opinion, one of the most commonly used methods of persecution in the Netherlands. Of the methods outlined earlier, poisoning is one of the easiest, and there is a limited chance of being caught. Since poisoning is non-selective, many non-targeted species are victims as well, among them Red List species (such as pine marten (*Martes martes*), white-tailed eagle (*Haliaeetus albicilla*) and red kite (*Milvus milvus*); and see Table 5.2 below) as well as dogs and cats.

In 2000, I (H. Jansman) wrote a booklet on how to recognise persecution and what to do if detected. The book was written for field biologists and law enforcement officers, since the latter had no prior knowledge of how to proceed (refer to Jansman 2000). A dramatic poisoning case in my own study area (where over 20 buzzards and a goshawk died) provided the impetus for writing the book, after so many things went wrong in the investigation, although in the end the criminal was apprehended. In this case, carbofuran was used. At the time, it could still be purchased at any farm supply store in the Netherlands with only a copy of one's identification card required. The granulate pellets were spread in the breast muscle of dead racing pigeons which were used as bait. Although forbidden or no longer available, other compounds are still used as poisons in the Netherlands (refer to the list below). As mentioned throughout this chapter, stockpiles last a very long time, or can be easily obtained from neighbouring countries. The reader has only to look at Figure 5.1 and Table 5.1 to understand this.

Although human-related crimes remain the priority of the police, some officers are allowed to devote a small portion of their time to 'eco-crimes' as well. In this regard, the booklet (i.e., Jansman 2000) is still considered a definitive reference, providing detailed instructions on how to search for carcasses and submit them for toxicological analyses. Some of the compounds known to have been used to poison wildlife in the Netherlands in the last ten years include:

Table 5.2 Species confirmed to have been poisoned with carbofuran in the Netherlands (1986 to 2010)

Species registered as casualties of carbofuran	Number of casualties detected
Common buzzard (*Buteo buteo*)	118
Western marsh harrier (*Circus aeruginosus*)	1
Northern goshawk (*Accipiter gentilis*)	18
Common kestrel (*Falco tinnunculus*)	1
Eurasian sparrowhawk (*Accipiter nisus*)	1
Eurasian magpie (*Pica pica*)	1
Pine marten (*Martes martes*)	1
Red kite (*Milvus milvus*)	1
Rough-legged hawk (*Buteo lagopus*)	1
White-tailed eagle (*Haliaeetus albicilla*)	1
Beech/Stone marten (*Martes foina*)	4
Pine marten (*Martes martes*)	1
Red fox (*Vulpes vulpes*)	2

Source: P. van Tulden, Centraal Veterinair Instituut (i.e., Central Veterinary Institute), The Netherlands, 2011

- Aldicarb (+ carbofuran)
- Alpha-chloralose
- Alpha endosulfan
- Bendiocarb
- Brodifacoum
- Carbofuran
- Chlorpyrifos (and + carbofuran)
- Diazinon
- Difenacoum
- Difethialone
- Ethoprophos
- Ethyl parathion
- Methiocarb
- Mevinphos
- Parathion + carbofuran
- Pirimicarb
- Strychnine

Of these, aldicarb, carbofuran and parathion are most commonly detected. We were unable to find any registered mixtures of aldicarb/parathion and carbofuran, so these are likely to have been prepared by the perpetrators themselves. This may also be the case for the chlorpyrifos and carbofuran combination, though in this case, we are aware of at least one formulated mixture (see Archer, Bynom and Plapp 1994). Before 2000, strychnine and alpha-chloralose were also often detected. Table 5.2 lists the species known to have been poisoned with carbofuran in the Netherlands between 1986 and 2010. The common buzzard is the most ubiquitous/populous bird of prey in the Netherlands, the most frequently reported as poisoned, and, as such, likely the most affected species as well.

5.3.3 Detection of carbofuran and other compounds in wildlife carcasses

Table 5.3 shows the number of wild animal carcasses submitted for analysis to the Centraal Veterinair Institut (CVI, www.cvi.wur.nl) in which carbofuran was detected, between 1986 and 2010. The number of poisoned wildlife submitted relative to the number of confirmed carbofuran casualties indicates that other products (e.g., parathion and aldicarb) are more frequently used in the Netherlands.

It is not easy to arrange for a carcass to be analysed for evidence of poisoning, especially since it can cost anywhere from 75 to 500 euro (between 105 and 700 USD) per sample. The lowest cost provides a postmortem evaluation, and at the highest cost, samples can be analysed for up to five groups of poisons (i.e., carbamates, carbamoyloximes, alpha-chloralose, strychnine, coumarin derivatives and lead). Law enforcers now have very sparse budgets, so analysis is only authorised if there is a potential offender in sight. Since this is hardly ever the case, this makes it difficult to resolve the issue, leading to the considerable frustration of many field biologists and volunteers.

Carcasses are typically submitted to CVI for necropsy, then for chemical analysis using GC/MS or HPLC-DAD (i.e., HPLC with diode array detection). CVI coordinates the study of all issues related to both legal and illegal use of pesticides. In only a fraction of the cases that have been studied (even when poisoning is confirmed) has an offender been charged and found guilty. Next, no centralised database (e.g., police database) exists where one could search for incidents of persecution, so we only gain a vague idea of how many cases are successfully enforced from what is published in newspapers.

Fortunately, the Dutch working group on birds of prey (www.werkgroeproofvogels.nl) has a base of enthusiastic volunteers who monitor an impressive number of nests each year (10 to 80% of all nests, depending on the species). Persecution of birds of prey is therefore very thoroughly studied and most cases are detected, which provides a good sense of the scale of poisonings occurring in the Netherlands.

5.3.4 Recommendations

To address persecution and poisoning in the Netherlands, we would recommend increasing the number of law enforcement agents that are dispatched to the countryside. There should also be fewer logistical and financial barriers to recovering carcasses of animals when poisoning is suspected to have caused death. The current penalties/fines are not severe enough, and should be raised accordingly. Finally, cases should be better documented so that any existing patterns can be identified. Ultimately, until our politicians and public leaders see persecution and poisoning of wildlife as a relevant issue, even if it is not directly harmful to humans, we do not feel that many people will take this issue seriously.

Table 5.3 Number of wildlife carcasses in which carbofuran has been detected in the Netherlands (1986 to 2010)

Year	Number of poisoned wildlife submitted for analysis	Number of carbofuran casualties	Number of animals baited with carbofuran
1986	173	0	1
1987	215	0	0
1988	149	0	0
1989	219	0	0
1990	101	0	0
1991	224	0	0
1992	197	0	0
1993	221	0	0
1994	156	6	4
1995	222	25	6
1996	332	1	2
1997	377	5	3
1998	288	21	6
1999	231	3	4
2000	154	1	1
2001	108	4	0
2002	183	21	10
2003	249	4	0
2004	139	9	7
2005	104	16	8
2006	217	21	8
2007	105	8	2
2008	97	4	2
2009	67	4	1
2010	88	1	5

Source: P. van Tulden, Centraal Veterinair Instituut (i.e., Central Veterinary Institute), The Netherlands, 2011

5.4 Initiatives underway to protect wildlife from carbofuran poisoning in Austria

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5.4.1 Introduction

During the 1990s, the number of illegal poisoning incidents in Austria increased rapidly. Dogs and cats, more likely to be reported than many other species, followed by common buzzards, foxes, stone martens (*Martes foina*), marsh harriers, white-tailed eagles and Imperial eagles (*Aquila*

heliaca) were most affected. There are two groups of perpetrators in Austria. First, there are hunters who poison animals such as foxes and martens because they view them as competitors. Small game hunting is practiced by farmers, local people and businessmen alike and it is especially popular in the lowlands of eastern Austria. Many hunters there believe that if they reduce the number of foxes and martens, the hare and pheasant populations will thrive (a situation encountered throughout Europe, as reflected in the other sections in this chapter). Then, there are often disputes between neighbours in settlement areas which may lead to retaliation, for example one person poisoning the dog of his neighbour (another common scenario across Europe). In this case, most of the poisoning incidents are reported from open landscape (as opposed to settlements), however, baits are rarely left in open fields. Instead, they tend to be placed near feeding stations for game, close to hunting towers, along hedges and field margins, near tracks and roads, often close to hunting territory borders. Dogs out for walks often come into contact with poisons this way.

5.4.2 Initiatives underway to generate awareness about, and monitor incidents of, carbofuran-related wildlife mortality in Austria

The poisoning incidents of the 1990s led World Wildlife Fund (WWF) Austria, together with BirdLife Austria and the animal advocacy NGO 'Vier Pfoten' (translation: Four Paws) to initiate the 'Vorsicht Gift!' project (translation: 'Beware Poison!' (see http://www.wwf.at/de/seeadler/ and http://hilfe.lebensministerium.at/article/articleview/42661/1/7135, the website of the Ministry of the Environment, and see Figure 5.2). The project began in 1999, with the overall aims of generating awareness about the illegal use of carbofuran against mammalian and avian predators, improving the prosecution rate against offenders and reducing poisoning incidents overall. A major reason for WWF involvement in the poisoning issue was the fact that poisoned baits emerged as a serious threat to endangered raptors such as the white-tailed eagle and the Imperial eagle. Indeed, the populations of both species had just started to recover when the poisoning wave began, causing an unsustainable number of casualties.

Since 2003, the project has been financially supported by the Austrian Federal Ministry of Environment and conducted in close cooperation with the Austrian Hunters Association (www.ljv.at), the police and the Raptor and Owl Rehabilitation Centre of Haringsee (www.egsoesterreich.org). The project consists of four elements:

1. Documenting poisoning incidents
2. Operating the 'Beware Poison!' hotline
3. Coordinating the 'Beware Poison!' network
4. Conducting media outreach and raising awareness

WWF Austria has created and is maintaining a database to document and monitor wildlife poisoning over the long term. Interested parties may obtain information from the database by written request from WWF Austria. Since the campaign began in 1999, carbofuran (which was banned in Austria as per EU Directive 2007/416/EC) has been detected in nearly 80% of the poisoning cases, whether as the cause of death or in regurgitated matter. In some cases, the regurgitate of dogs successfully treated for poisoning was analysed and in other cases, dogs were sampled because they presented symptoms that were typical of carbofuran/carbamate poisoning and their condition improved after treatment (refer to Chapter 2 for a discussion on symptoms and treatment). Strychnine and zinc phosphide, which were (and still are) used as rodenticides, were detected in the remaining 20% of

Figure 5.2 Leaflet from the 'Vorsicht Gift!' (Beware Poison!) project. Reproduced with permission of WWF Austria

cases. These particular incidents were not hunting-related or retaliatory but instead occurred when farmers or other persons applied these products inappropriately/incorrectly, resulting in their consumption by non-target species. For example, we had a case where zinc phosphide-treated wheat was spread liberally in a field to kill voles and six starlings were poisoned (the details of this incident and others like it can be found in the aforementioned database).

5.4.3 Toxicological analysis of wildlife carcasses in Austria

If a dog or a cat is poisoned in open landscape (i.e., outside a settlement area) or a wild animal is found, the Hunters Association pays for the analysis. This is carried out by the Research Institute of Wildlife Ecology, which is part of the University of Veterinary Medicine in Vienna. If a dog or cat is poisoned in settlement areas the owners themselves have to pay. In some cases where it is unclear whether or not a domestic animal was poisoned in open landscape, WWF Austria assumes the cost. In this case, the analysis is instead done at the Institute of Pharmacology, Toxicology and Pharmacy, Department of Veterinary Sciences (Ludwig-Maximilians University of Munich, Germany; see http://www.pharmtox.vetmed.uni-muenchen.de/institut/index.html). At both facilities, the samples are first screened for AChE inhibitors by using thin layer chromatography (TLC), followed by verification of carbofuran by GC/MS.

In 2010, a total of 220 samples were analysed in Munich, most of them submitted from (in decreasing order) Germany, Austria and Switzerland. Of these samples, 52 tested positive for AChE inhibitors and carbofuran was detected in 62% of samples (i.e., 32/52, see Table 5.4). Other frequently detected AChE inhibitors were: methiocarb, paraoxon and methylparaoxon. All of the wildlife species were found dead and organ samples were submitted for toxicological analysis after autopsy. Pathological-anatomical findings associated with carbofuran were tracheal edema, congested lungs and punctate haemorrhagia in the lung, brain and heart muscle. With the exception of the saker falcon (which came from Austria) all wildlife samples were received from Germany (where carbofuran use is no longer permitted, see Table 5.1).

Carbofuran was also detected in one horse from Germany and three horses from a national (and prominent) stud farm in Hungary. All horses displayed severe signs of acute colic and died immediately. In the samples from the Hungarian stud farm, carbofuran concentrations of 1.22, 9.9 and 10.2 μg per gram liver material was detected. A single carbofuran intoxication case originated from Switzerland in 2010 (where carbofuran is still registered for use, see Table 5.1). The samples were from a cat, but the source of intoxication is again unknown. In general, the laboratory receives only a few samples from Switzerland, most likely because shipment is very complicated and parcels are often detained at the toll point in Frankfurt (Germany). Even when samples are packed with dry ice, they still often arrive in an advanced state of decomposition.

5.4.4 Conclusions

The police and the Federal Office of Crime Investigation are also important cooperative partners in the Beware Poison! project. In addition, WWF Austria has a cooperation between the Austrian Hunters Association, the Ministry of the Environment and many more partners. Even if only a few of the culprits have been caught, offenders have at least been charged in at least some cases. Normally, a fine of between 1 000 and 5 000 euro is imposed (between 1 500 and 7 000 USD). And, if an offender is a hunter, they lose their hunting permission for a number of years, depending on the protected status of the species in question. More needs to be done, but the partnerships described within this section are helping to gather important information about wildlife poisonings in Austria which in turn can be used to educate the public and incorporated into investigations.

Table 5.4 Carbofuran poisoning incidents detected at the Institute for Pharmacology and Toxicology in Munich (2010)

Species/sample type	Number of samples received
Domestic cat (*Felis catus*)	8
Domestic dog (*Canis familiarus*)	8
Domestic horse (*Equus caballus*)	4
Bait material	3
'Bird' (*species unidentified*)	2
'Duck' (*species unidentified*)	1
Pheasant (*species unidentified*)	1
'Raptor' (*species unidentified*)	2
Golden eagle (*Aquila chrysaetos*)	1
Saker falcon (*Falco cherrug*)	1
Rabbit (*Oryctolagus cuniculus*)	1

Source: H. Ammer, Institute for Pharmacology and Toxicology in Munich, 2011

5.5 Use of specialised canine units to detect poisoned baits and recover forensic evidence in Andalucía (Southern Spain)

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5.5.1 Introduction

As is typical of many Mediterranean countries, hunting is very popular in Spain, and undertaken at all levels of Spanish society. Hunting is permitted in almost 80% of the country, and in many areas there is a conflict between human and wildlife predators. The use of poison against predators is illegal in Spain, and it is considered a prosecutable offence, in contravention of national regulations (Ruiz, Ortega, Valero et al. 2010). Nonetheless, some hunters or gamekeepers leave poisoned baits in the wild with the intention of killing foxes, mongoose (*Herpestes ichneumon*), feral cats/dogs and other generalist carnivores that prey upon wild rabbits (*Oryctolagus cuniculus*) and red partridge (*Alectoris rufa*). This illegal practice increased in the late 1980s, after outbreaks of viral diseases elicited pneumonia in (and decimated) the wild rabbit populations in Spain, which further increased competition/conflict.

The second basis for poisoning in the country is related to 'protecting' livestock from predators. As is the case in many European and African countries (see other sections of this chapter and refer to Chapter 3), poisoning is regarded as a first option to deter carnivores from attacking livestock. While agriculture/farming may not contribute significantly to Spain's overall economy, these

practices are very important locally, in remote mountainous areas, where sheep are primarily grazed. In Andalucía, farming and hunting-related poisonings account for 25 and for 60 to 70% of the cases recorded, respectively (Ruiz, Ortega, Valero et al. 2010). The remaining percentage is attributed mostly to incidents of personal revenge (e.g., following disputes between neighbours). Indeed, in the Mediterranean it is not at all uncommon to use poison to solve personal problems either directly (against people) or, more frequently, to poison an individual's livestock and/or domestic animals.

Table 5.5 summarises the types of poisons used in Andalucía (from 2008 data), which can also be considered to represent the situation across Spain. Use of carbamates (e.g., aldicarb, carbofuran and methomyl) and organophosphorus compounds (e.g., methamidophos) predominated overall (Ruiz, Ortega, Valero et al. 2010). The increase in the use of these compounds can in part be linked to a decrease in the availability of strychnine, which was banned in 1998 in the EU (according to Biocidal Products Directive 98/8/EC). Although most of the compounds used are illegal under EU regulations, stockpiles remain and a black market also exists. It should be noted that some of the organochlorine residues that are detected originate from past use and environmental contamination rather than active use of a compound as a bait/poison. In such cases, the distinction can be made by comparing residues (and concentration levels) detected from the carcass with those in the bait used to poison the animal.

The dramatic increase in the use of poison baits led to the virtual extirpation of certain species (i.e., Egyptian vulture and red kite) from large areas in the late 1990s, while the population and range of others were seriously compromised. The Spanish imperial eagle (*Aquila adalberti*), black or cinereus vulture (*Aegypius monachus*), red kite (*Milvus milvus*), Egyptian vulture (*Neophron percnopterus*), griffon vulture (*Gyps fulvus*) and wolf (*Canis lupus*) are among the species that were affected. More information about such threats to Spanish vulture and eagle populations can be found in Gonzáles, Margalida, Maños et al. 2007, Hernández and Margalida 2008, Margalida, Heredia, Razin et al. 2008 and Hernández and Margalida 2009, among others. In response, the national and regional governments devised strategies and policies in 2000, to prosecute poisoning offenders and to stop/reduce incidence of poisoning. In this same spirit, the Government of Andalucía launched a special programme simultaneously, to address this problem from all sides. From a legal perspective, more restrictive regulations were introduced, and a concerted effort has been made to prosecute offenders. The penalties are compelling, for example fines can reach up to 200 000 euro, and there is also the very real possibility of spending time in prison. Presentations and strategically placed signs/panels, and media outreach to disseminate information in the press and on television are just some of the educational measures being enacted (Ruiz, Valero, Sáez et al. 2010). Alternative 'control' methods are also being promoted. For example, the use of snares and traps/cage traps will soon be legalised (but under restrictive conditions) as a substitute means of reducing predator populations. There is also an increased effort to detect baits, specialised detection teams are being trained, and advanced forensic methodologies, investigative and police methods are being developed, among many other initiatives. To date, incidents of poisoning have been reduced by 40% and the more

Table 5.5 Summary of poisons used against wildlife in Andalucía (2008)

Class of compound used	Percentage detected (%)
Carbamate	76
Organophosphorus	12
Rodenticide	5
Organochlorine	4
Pyrethroids/pyrethrin	2
Phenols	1

Taken from Ruiz, Ortega, Valero et al. (2010)

vulnerable species (e.g., imperial eagle, griffon and black vultures) are recovering regionally and, in some cases, locally (Ruiz, Ortega, Valero et al. 2010 and the government website mentioned below). Further information about the population status of these species can also be found on the Birdlife Spain website (SEO/BirdLife; http://www.birdlife.org/worldwide/national/spain/index.html).

5.5.2 Integration of canine units in the anti-poisoning strategy of the Government of Andalucía

The detection teams initially dispatched by the Spanish regional government now some ten years ago or more, were only able to identify a fraction of the baits left out in the wild to kill wildlife such as mongoose and foxes. When the idea came to use dogs to detect poison, it just seemed to be a question of common sense. We started our canine training operations in 2002 and by the beginning of 2004 our first unit joined us in the fight against poisoning. We are currently leading an important long-term government project (initiated in 2000: 'Estrategia Andaluza de Lucha Contre el Veneno') focused on reducing the incidence of illegal poisoning in wildlife in the Andalucía Region (http://www.cma.junta-andalucía.es/medioambiente/site/web/menuitem.a5664a214f73c3df81d8899661525ea0/?vgnextoid=2c1c638f0a77a110VgnVCM1000000624e50aRCRD&vgnextchannel=c715dfd0aedac110VgnVCM1000001325e50aRCRD&lr=lang_es). The programme, which employs five people full-time, has a 1.2 million euro budget. We have 18 dogs in three units, the third and most recent was ready for action by the spring of 2011.

Dogs in our anti-poisoning unit are trained in the same way as dogs in other units (e.g., detection of drugs and explosives or recovery of victims following earthquakes). The only significant difference is that under no circumstances can the dogs in our unit be rewarded with food, otherwise they might be poisoned themselves. Instead, they are rewarded with playing. The reaction of a dog that detects a bait/carcass or poison trace very much depends on the individual. Some bark energetically or just sit down whereas others become playful, however, all of the dogs anxiously beg for their reward (i.e., playing). We have never yet lost any dogs to poisoning, which can partly be attributed to the professionalism of our handlers and their love for the dogs. Following the success of our Spanish units, we have received many requests from other regions to train dogs for deployment to other Spanish and European areas where poisoning is also a problem. So far, our dogs have been dispatched to the Canary and Balearic Islands. Likewise, we have trained dogs for other Spanish regions (e.g., the Pyrenees) as well as for Italy and Greece.

The training period of a dog can span anywhere from six months to one and a half years, depending on the individual. There is no specific type of dog that is more or less suited to this type of work (see Figure 5.3) and each trainer has their own source of dogs. The trainer determines the capabilities of each individual when they are puppies. Our dogs can detect bait that has been laced with (and carcasses of animals poisoned by) carbofuran and a variety of different compounds commonly used to kill wildlife (e.g., aldicarb and methomyl) (see Figure 5.4). They can locate very small (e.g., shrew-sized) animals that have been secondarily poisoned and are even able to detect the very spot on the ground where carcasses or baits were in the past. We also take dogs to inspect the vehicles, homes, and other holding areas (such as barns and workshops) of suspects. A Judge's permission is required to enter an individual's home, which we request in the event of a serious incident. As a result of our work and our presence, many poisoners remove baits and dead animals on a daily basis, to avoid detection. This in itself reduces the number of poisoning incidents overall. Today, these canine units are an essential part of the work carried out by the government against poisoning, detecting some 70% more baits (Ruiz, Valero, Sáez et al. 2010) (Figures 5.5 and 5.6).

Every year our results are released in an annual report, which carefully details all the data collected (visit the aforementioned website for further details). In 2010, the dogs made 439 emergency/routine inspections in the wild. An emergency inspection is one made as soon as we are informed

Figure 5.3 The specialised canine units of Andalucía are made up of different types of dogs

Figure 5.4 The dogs in the units are trained to detect baits such as this one, which have been laced with compounds commonly used to kill wildlife

that a poison has been found, where we immediately take the dogs and police to enact legal procedures. By contrast, routine inspections are conducted on a 'dissuasive' basis, and we annually design and plan a schedule of hotspots to visit according to their past poisoning profile, or where threatened species are present, and an increased presence is warranted (Ruiz Garcia, Valero Garruta, Sáez Manzano et al. 2010). Poison was detected on 88 occasions (83% being aldicarb, carbofuran and methomyl). Aldicarb tends to be most often detected, however Andalucía spans a very large area and it is not unusual that carbofuran, methomyl or even other compounds are favoured instead in some places.

Figures 5.5 and 5.6 The specialised canine units are an integral part of the work carried out by the Government of Andalucía in its efforts to combat wildlife poisoning

5.5.3 Use of forensic procedures and techniques in the field and the laboratory

Since, as a general rule, there are few or no witnesses to report those putting out poisoned baits in the field, and evidence of poison tends to surface only once there have been casualties, our investigation units have to rely upon typical police investigation methods. The most important facet of the work

undertaken under our programme is forensic, using advanced techniques to identify criminals (e.g., DNA, fingerprints, ballistics), that are exactly the same procedures commonly used to solve human crimes. In mid-2010, we published and distributed a handbook of investigative methods in wildlife crimes for police forces specialising in wildlife-related crimes (i.e., Fajardo and Martín 2010). The handbook (a second edition was released in May 2011) was very favourably received, and there was a high demand for it within the rest of Spain and from Portugal, France and Italy. In addition, the managers of police forces in these countries are in the process of training specialised teams, some even in the framework of an EU Life initiative. We have also developed a very good advanced course to train police bodies in specialised on-site forensic aspects and techniques.

Any evidence recovered from the field is collected according to very strict and specific protocols (Fajardo and Velasco 2010). All findings (e.g., baits and carcasses) are then submitted to our forensic laboratory, the Centro de Análisis y Diagnóstico (CAD) for an initial screening. In addition to other compounds of concern/interest (e.g., anticoagulants), samples are initially screened for over 100 organophosphorus and carbamate compounds using GC/MS/MS and UPLC-MS/MS. This is in accordance with EU Directive 2002/657/CE, which stipulates that carbamates and non-carbamates must be investigated using liquid chromatography (HPLC, UV/MS) and gas chromatography (ECPD, NDP/MS), respectively. The costs of the analyses are assumed entirely by the programme, and vary greatly, depending on the amount and type of evidence submitted, and whether or not external confirmation is required. As a guideline, costs can range from 60 euro (for positive confirmation only) up to 600 euro. Compounds that have been detected from baits recovered in the field include:

- aldicarb
- brodifacoum
- bromadiolone
- carbofuran
- chlorfenvinphos
- chlorpyrifos
- diazinon
- difenacoum
- dimethoate
- diphacinone
- endosulfan
- ethyl parathion
- lindane
- methamidophos
- methiocarb
- methomyl
- methyl parathion
- pirimicarb
- p,p’-DDE
- strychnine

If the CAD does not detect poison but we still strongly believe, on the basis of forensic findings at the site, that the cause of death was poison, then we submit the samples to two different laboratories in Spain for further analyses with more powerful techniques. In 2010, poison was detected externally, in 38% of baits/carcasses not detected in our laboratory. Samples would be submitted externally, for example, due to the presence or absence of certain insect species (see Figures 5.7 and 5.8), their distribution on the carcass, and a finding of dead insects near the digestive tract, which can all be indicative of poisoning. Body posture (e.g., clenched talons, facial grimace) are also highly diagnostic (see Figures 5.9, 5.10, 5.11). Poisonings that stem from anger or that are carried out by inexperienced offenders are usually more easily detected, by virtue of the fact that an excessive amount of compound tends to be used. By contrast, professional poisoners typically use very small doses of a single toxin, which is naturally more difficult for us to detect.

Figures 5.7 and 5.8 The presence or absence of certain insect species can indicate poisoning occurred

Figures 5.9, 5.10 and 5.11 Body posture and expression (e.g., facial grimace) can also be indicative of poisoning

5.5.4 Conclusions

The implementation of the canine detection units, as part of the overall anti-poisoning strategy, has been particularly effective in helping us gather more information and better understand/address the magnitude of this problem. Perhaps most importantly, the existence and efficiency of these units is a powerful deterrent that often prevents criminals from leaving poisoned baits in the field. Since early 2000, we estimate that the number of poisoning events have been reduced by up to 40%. All but one of the species vulnerable to poison (the Egyptian vulture, which is still in decline, but less acutely than before) have recovered significantly. However, between 2001 and 2008, 90 species (including 55 avian, 25 mammalian, three reptilian, six piscivorous and one invertebrate) were poisoned within Andalucía (Ruiz, Ortega, Valero et al. 2010). There is still work to be done in this area, but we have excellent resources and personnel, and remain committed and united in our fight against poisoning.

5.6 Sociopolitical and rural influences on the management and monitoring of carbofuran and its use to poison wildlife in Hungary

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5.6.1 Introduction

In Hungary, political and social movements have had far-reaching impacts on the peoples' perceptions towards the way that traditional rural livelihoods are carried out and pesticides are managed. Most people in rural areas seem to have a certain respect for things labeled as 'poison'. It may be just as important that, as a legacy of the methods followed in the old, socialist-industrial-agriculture system, the rules of access and use of chemicals are quite strict in Hungary. In a lot of 'rural' areas of expertise (e.g., farming and forestry regulation, hunting) there seems to be a tradition of doing things that predates even the intensive industrial agriculture of the socialist era that ended around 1990, with strict procedures, traditions, code of ethics and tremendous pride among the members of these 'clubs'. So, for example, someone in Hungary who had graduated from the only, absolutely tradition-fixated forestry university would provide the impression that he (and usually not she) has a kind of self confidence that is stereotypically possessed by doctors or lawyers. This very controlled way of organisation and talking and thinking also seems to apply to older veterinarians here.

Plant protection was quite a centralised business here, especially during the so-called socialism before 1989. One could almost say that it was run like a military organisation, and both the experts of this State-controlled, national plant protection service, and the plant protection experts working at the different collective farms were highly skilled, taking a lot of pride in all their specialist knowledge. The collective farms were created by nationalising private lands when the communist (later socialist) regime took hold of Hungary after the Second World War. By the 1970s these socialist enterprises were characterised by intensive, large-scale production, and in many cases they were headed or at least managed by skilled experts, and though production was geared mostly towards quantity instead of quality (the most important market being the Soviet Union), produce from some of the 'top' collectives and State farms were successful in Western markets as well.

All these sociopolitical elements are mentioned to convey the feeling that there is a longstanding tradition and culture of using pesticides in Hungary, which should make any accidental or unintentional poisonings quite unlikely. Unfortunately, the demise of the collective farms meant that huge amounts of these potential poisons were suddenly outside the realm of accountability. In this regard,

we could also say that the situation bears some similarities to the problems with the nuclear weapon stockpiles of the former Soviet Union.

Before the EU-wide ban in 2007, access to anything with carbofuran in it was restricted. The earliest registration of a carbofuran product within the government database was in 1973, and, between that time and the ban, five chemicals including carbofuran or 'carbofuran-like' (i.e., the chemically similar carbosulfan) were used legally as agricultural pesticides in Hungary: Agrofur (40% carbofuran), Chinufur 40 FW (40% carbofuran), Furadan 10G (10% carbofuran), Furadan 4 F (40% carbofuran) and Marshal 25 EC (25% carbosulfan) (Central Agricultural Office, personal communication, 2011).

Only people with specific education and licenses could buy, store and apply these products or they were required both to oversee its application and to log the use of it. Such logs had to be kept at the farms themselves so that they could be shown to the authorities if requested. Transportation, storage and disposal were also strictly regulated, until the demise of many of the former collective farms in the last two decades. Sometimes the pesticide storage facilities at these farms were left abandoned, and quite a lot of the pesticides were, let us say, 'redistributed' among the local population.

5.6.2 Incidents of carbofuran-related wildlife mortality in Hungary

According to the database of BirdLife Hungary (MME), between 1998 and 2008, 77 different wildlife poisoning cases were reported. Aside from a single case of negligent pesticide use by a farmer and three reported cases of secondary lead poisoning (from lead shot) almost all of these cases were the result of deliberate poisoning. Carbofuran was detected in 75% of the poisoning cases (i.e. 58/77). New cases have emerged since then, and are being recorded every year. In contrast to some of the other contributions offered in this chapter, here, such poisonings tend not to target birds of prey. Instead, they tend to be motivated by the imperative to protect small game species from foxes and corvids, although it must be noted that one of the poisoning incidents occurred because a hobbyist had wanted to protect his pigeons from birds of prey. The victims' susceptibility is mainly influenced by the method of poisoning used. Small animal carcasses (e.g., a pheasant) or scraps of meat generally serve as bait and thus animals such as foxes and various birds of prey, who are drawn to such items, are readily poisoned.

BirdLife Hungary reported that 36 Imperial eagles have been found poisoned and nine more are assumed to have died either directly or indirectly as a result of poisoning since 2005, when the first such case was reported since the 1970s. The population status of Imperial eagles in Hungary is now seriously threatened by an increasing trend of persecutions which is very unfortunate because the species had previously been considered a real conservation success story. Mortality from poisoning is much higher than from other forms of persecution. For example, during the same period 'only' four eagles were shot and two nests with clutches were fired upon. In total, an estimated 54 Imperial eagles have been the victims of persecution incidents during the last years, equivalent to 23.1% of the national and 14.2% of the European Union breeding population size in 2010. In addition to Imperial eagles, 932 other protected birds belonging to 20 different species (e.g., 65 white-tailed eagles (*Haliaeetus albicilla*), 12 saker falcon (*Falco cherrug*), 271 common buzzard (*Buteo buteo*)) have been found poisoned in Hungary since 2000 (Horváth et al. unpublished data). And these numbers are very conservative because only a fraction of all poison deaths are reported to nature conservation organisations.

5.6.3 Analysis of wildlife samples for poisons and other incidents of poisoning in Hungary

In recent years, BirdLife Hungary has used the services of a single laboratory in Budapest (M. Horváth, personal communication, 2010). Tests cost about 10 000 HUF (USD 50) per sample, and Birdlife Hungary primarily assumed the costs during the first few years when the poisonings

were unfolding. Since around 2008, however, they have developed an arrangement whereby the National Parks (NP) cover most of the costs since Hungary's territory is divided between different NP directorates which act as authorities in legal cases such as this. Of course, money is a problem for the Parks as well, so samples of the 'less valuable' animals (e.g., foxes and buzzards), are often not tested at all. This makes it quite difficult, if not impossible, to prosecute these cases, and the emphasis should be on the fact that a poison was illegally used rather than on the species that died as a result. Up to now, the police have paid for the analyses in a single case, which should actually be the norm.

Other related cases of carbofuran poisoning also surface in the media from time to time. For example, between 2003 and 2006, a farmer's cows (and several buzzards) were poisoned, possibly by a neighbour (http://www.szabadfold.hu/cikk?5522). Interestingly, at the time of the incident, the farmer complained that the dead buzzards received greater media attention than his cows. More recently, in 2009, a carbofuran-related fish kill (40 tons) was reported at an artificial lake near Budapest that was popular with anglers (http://www.szabadfold.hu/gazdanet/ki_pusztitott_el_40_tonna_halat_csepelen).

5.6.4 Conclusions

Poisoning and persecution are jeopardising the success of conservation efforts, as shown by the decline of the Imperial eagle population. Despite the fact that the use of carbofuran is now prohibited within the country, the product continues to be implicated in many wildlife poisoning incidents. Overall, the problem in Hungary lies not with the laws or regulation, but rather with the enforcement and prosecution of cases, largely because the police often lack the expertise and resources needed to deal with cases. This situation must be addressed so that conservationists can again go back to documenting an increase in the numbers of healthy birds of prey such as the Imperial eagle, rather than resigning themselves to counting and collecting their carcasses.

5.7 Leisure-based human-wildlife conflicts arising from the introduction of game species and repercussions to vultures across Croatia

Gordana Pavokovic

Member of the former Committee for the illegal usage of poisons in nature

5.7.1 Introduction

My first deep involvement with a poisoned bird came about when a Eurasian griffon vulture, ringed as C15 (see Figure 5.12), landed on the roof of a small house near the beach in Beli, on the Island of Cres in Croatia, in the summer of 2001. At that time, I was working in a Vulture Recovery Centre on Cres. After C15 lowered his head and let us capture him, he was brought to the centre. All the volunteers who worked with this bird at the centre will remember C15 (see Figure 5.13). During the first night, there were no visible symptoms of poisoning, but in the morning, we found C15 lying on his back. During the day, vomiting increased, and this was accompanied by neurological symptoms, ranging from mild head tremors, a repeatedly twisting head and body (in one direction, to the right, in a circular motion) with wings half spread.

C15 was also observed walking backwards, had a lack of coordination, had muscle spasms, and exhibited hyper-salivation and muscle weakness. Severe convulsions increasingly weakened the

Figure 5.12 Eurasian griffon vulture C15 on the roof of a small fishery house on the beach of Beli, Island of Cres, during the summer 2001
Photo taken by Gordana Pavokovic

Figure 5.13 Eurasian griffon vulture C15 with a volunteer at the Recovery Centre on Island of Cres
Photo taken by Gordana Pavokovic

bird, and I spent a second night holding C15's body and head, hoping he would survive. During the following day, his state deteriorated until he eventually died of respiratory failure. Before he died, I even tried to revive C15, mouth to beak, because I was desperate. At that time, I did not know what poison had caused his death, and while at the centre we made hundreds of calls asking for help and advice, but no one then believed that griffon vultures could be poisoned.

The symptoms of C15, and those of other griffon vultures that followed him, led us to suspect poisoning was being caused by organophosphorus or carbamate compounds (OP/CB). Finding a laboratory to prove this was, however, difficult. C15 was the first bird brought to the Recovery Centre with such neurological symptoms (which are typical of OP/CB poisoning; as also detailed in Chapter 2), but for him we were not able to confirm poisoning in the laboratory. However, at that time, no laboratories in the country were set up to test tissues from wild birds suspected to have been poisoned.

The Committee for 'illegal poisoning in nature' was established within the Ministry of Environmental Protection and Physical Planning on 20 March 2001. Within the Committee were experts (hunters, veterinarians, policemen, doctors, ornithologists, foresters, biologists and toxicologists) who made proposals regarding illegal poisoning in nature. Unfortunately, the work of the Committee was halted after elections were held in 2003 and the government changed. The Minister who was elected showed no interest in the poisoning issue at all. The Department for Nature Protection also changed quickly to the Ministry of Culture. Since C15, many cases of illegal OP/CB use have been detected, often involving carbofuran. Such cases and some of our other experiences are outlined in this section. To provide geographical perspective, a map detailing the areas mentioned in this section is provided (see Figure 5.14).

Figure 5.14 Map of Croatia, prepared by John C. Nelson and Wayne E. Thogmartin, United States Geological Survey, Upper Midwest Environmental Sciences Center

5.7.2 Past registration and current use of carbofuran in Croatia

Unfortunately, it is not simple to establish exactly when carbofuran was first used in Croatia, or to identify those holding such information. Neither the relevant Government Ministry nor the Plant Research Institute knew the answer to this question. Regardless of this, to comply with EU standards (substances not present in Annex I of EU Directive 91/414/EEC), Croatia essentially began to ban the use of carbofuran in 2007. Before this, its primary use was for plant protection against pests. The formulation Geocid 350-F was used to eliminate *Agriotes spp*. (a type of beetle) in corn, except if the corn was destined for animal feed. It was also used on sugar cane during seeding, and to reduce maize leaf weevil (*Tanymecus dilaticolis*) and sugarbeet flea beetle (*Chaetocnema tibialis*). Geocid G-5 was used on soil borne insects during seeding of corn, sugar cane and sunflower. It was also used on tobacco pests and for potato protection. Geocid ST-35 was used as a concentrated suspension on sugar cane seeds, and on corn and sunflower to eliminate soil pests.

Most carbofuran formulations were banned in Croatia on 31 December 2007. However, its sale and storage was allowed for the following 18 months, with a final ban becoming effective on 31 June 2009. Geocid can still be sold until 2016 in a liquid form, but the granulated form (G-5) is now banned completely. Table 5.6 shows the formulations that were available before the ban. Chromos Agro is a Croatian producer of Geocid. Arysta Life Sciences, the producer of Siux, is a foreign producer, with headquarters in Japan.

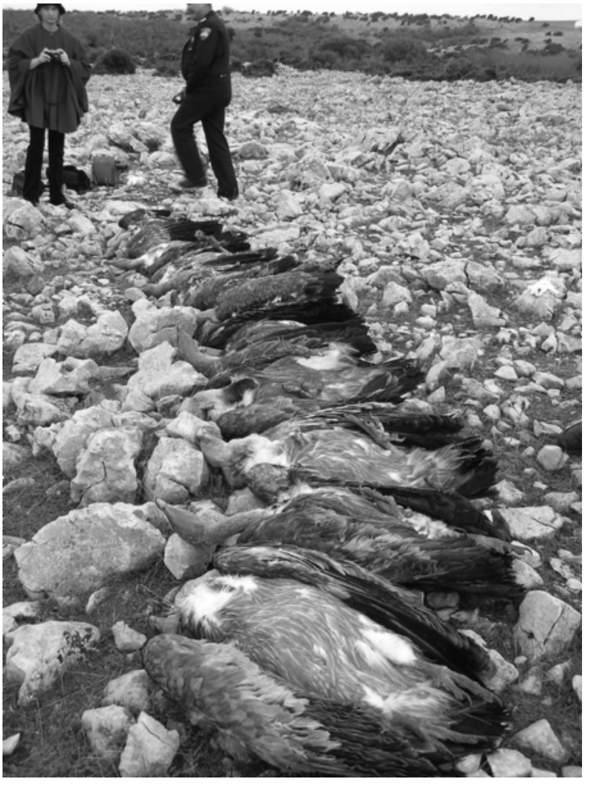
5.7.3 The use of carbofuran as a poison in relation to other compounds in Croatia

The first significant incident of multiple case wildlife poisoning with carbofuran was documented for Eurasian griffon vultures (see Figures 5.15 and 5.16). On 17 December 2004, on the Island of Rab, ten dead griffon vultures (six adults, two subadults and two juveniles) were found. One adult was barely alive, and in a very bad state (Figure 5.17). This griffon was taken to the Recovery Centre, but died two days later. All dead birds were taken to the Faculty of Veterinary Medicine at the University of Zagreb. The assumption after autopsy was that the birds had been poisoned, since the griffons were in good body condition and no ammunition was found in their bodies on X-ray. This incident is recounted in Pavokovic and Sušic (2005).

Although the issue of illegal poisoning had been raised since 2001, this was the first known incident of multiple case poisoning. A media campaign followed, which prompted police to begin a serious investigation. Before this incident, the police were generally dismissive of wildlife poisoning cases. The incident was covered by prime time TV news, which helped ensure the investigation continued. Police searched the area where the griffons had been poisoned, and found six more griffons in addition to a dead sheep and two dead buzzards. The sheep, buzzards and griffons were all discovered within 200 metres of the first group of birds. In total, two buzzards and 17 griffons were

Table 5.6 Formulations of carbofuran products available in Croatia before the EU-wide ban

Formulation	Producer	Representative	Registration validation up to	Allowed sale of products to producers	Allowed sale and usage to the final users up to
GEOCID 350 FL	Chromos Agro	Chromos Agro	09/12/2007	31/06/2008	31/06/2009
GEOCID G-5	Chromos Agro	Chromos Agro	09/05/2008	31/06/2008	31/06/2009
GEOCID ST-35	Chromos Agro	Chromos Agro	13/03/2007	31/06/2008	31/06/2009
SIUX 5 % (MG)	Arysta	Hed	16/02/2016	31/06/2008	31/06/2009



Figures 5.15 and 5.16 Eurasian griffon vultures poisoned with carbofuran on the Island of Rab on December 17, 2004
Photos taken by Trzezbor Piekutowski

Figure 5.17 The only living griffon vulture found during the poisoning incident with carbofuran on the Island of Rab in very bad state. This bird died two days later
Photo taken by Damian Nenadic

recovered from the area. GC/MS analyses of the crop and stomach tissues from all the vultures showed that the poison involved was carbofuran.

This was also the first case of wildlife poisoning proven in a forensic laboratory in Croatia. The first set of birds was tested in a private forensic laboratory, and subsequent birds were tested at the Centre for Forensic Research ('Ivan Vucetic'). The police immediately formed a team of eight experienced criminologists, and within two weeks they located an individual whom they suspected had baited poison onto the dead sheep. In the individual's house, the police found the same pesticide (i.e., carbofuran) as used on the bait. The suspect had a range of pesticides in his house. However, he was not an agriculturalist (i.e., he did not tend any crops) and so he did not have any legal need for them. The police also found carbofuran in houses owned by five more sheep herders in the same area. The State attorney decided to investigate the incident in detail and collected more evidence against the culprit for the court.

In Croatia, a 'price-list' for protected species exists by law. The 'fee' (fine) for killing a griffon is 40 000 kuna (Hrk), which is around 5 500 EUR or 7 300 USD. Therefore, damages were estimated at 17 griffons x 5500 EUR = 93 500 EUR. Further damages for the crime against nature were added. The total damage was then estimated at one million Hrk (around 133 000 EUR or 175 000 USD). On 27 November 2010, the main suspect was given a 660 000 Hrk (90 400 EUR or 120 000 USD) penalty. The court then acquitted him. If found guilty the suspect could have spent up to ten years in prison. However, in this instance, he was released without charge. The Judge stated that he could not be sentenced based on circumstantial evidence. The poison (i.e., carbofuran) was in the house, it was the same formulation as detected on the dead laced sheep (which was his), and the carbofuran found in the GI tract of the dead birds was also the same. But, a conclusive link to prove the individual put the carbofuran on that sheep did not exist. Hence, the police had circumstantial evidence and suspicion but could not convincingly 'prove' a firm forensic case.

In 2004, the Vulture Recovery Centre (on the Island of Cres) sent another griffon vulture with neurological symptoms to the Faculty of Veterinary Medicine at the University of Zagreb. There, they detected methomyl, which is also a carbamate. This case is discussed in Sabocanec, Konjevic, Srebocan et al. (2005). Thus, as well as carbofuran, people in Croatia are clearly using other

cholinesterase inhibitors. They can be easy to buy, there is no control exerted over their use, and no education is given as regards their proper use. In addition though, the issue of anticoagulant rodenticides must also be noted. Throughout Croatia, there are specialised firms for rodent control and these are authorised by the government. They are called 'DDD' firms, i.e., disinfection, disinsection (eradication of insects) and deratisation (eradication of rodents). These firms are very 'proactive', and put rodenticides out not only for an existing infestation, but also to prevent future infestations. They are paid in relation to the quantity that they put out, and not in relation to eradication results. Rather than preventing infestation by management, i.e., cleaning an area by removing rubbish, unused items or by cutting back vegetation to lessen infestation or the risk of infestation, extremely potent poisons are indiscriminately placed into the natural environment.

Further, while many substances are now forbidden as plant protection pesticides by the Ministry of Plant Protection, the Ministry of Health sometimes permits the same substances for use in communal hygiene (to supposedly protect human health and control rodents). Substances such as brodifacoum and flocoumafen are normally intended for use indoors, not outdoors (at least in the UK). In Croatia, rodenticides are left indiscriminately in basements, often on a paper tray, with no control. Figure 5.18 shows a photo from the Island of Hvar of a plastic bag filled with rodenticide that was left sitting on a wall in the rain. On other islands, rodent control employees carry a bucket filled with rodenticide and pass through the streets shouting 'Tko treba otrova?' (i.e., 'who needs poisons?'). The locals, who do not receive any instructions or training, place these potent toxicants into jars or plastic bags and use them as they see fit.

Recently, in April 2010, a jackal carcass was discovered on hunted ground adjacent to the Velebit Nature Park. The incident is reported by Reljić, Srebocan, Huber et al. (2010). The following day, a dead bear was found some 200 m away (from the jackal carcass, which had been removed). No injuries were visible on the bear, but traces of watery vomit were observed on the animal's front legs. At three locations nearby, beside a water source, bait was found which consisted of meat and bones upon which dark blue granules were observed. Two days later, the veterinarian from the Faculty of Veterinary Medicine at Zagreb and the police visited the site. An autopsy conducted on-site revealed bloating of the corpse, moderate autolysis and organ congestion due to blood coagulation. Samples were taken

Figure 5.18 Rodenticide baits left out on a stone wall on the Island of Hvar
Photo taken by Gordana Pavokovic

from the liver, kidney and the entire ligated stomach. The baits were also collected. The tissue samples and baits were sent to the police forensic laboratory. A small amount of bluish liquid was found in the bear's stomach. Carbofuran was detected in the stomach contents, and in the bait, (by GC/MS) and in the kidney and liver (by LC/MS). The mean measured concentration in these latter tissues was 2.695 and 12.650 ppm, respectively. On the basis of these concentrations in liver and kidney, the short distance between the bait and the bear carcass, Reljić, Srebočan, Huber et al. (2010) surmised that the animal had succumbed to carbofuran poisoning. This represents the first record of a bear poisoning case involving carbofuran bait in Croatia, although it is likely that the bait was not intended for the bear.

5.7.4 Threats to biodiversity, livelihoods and tourism on the Croatian islands

The main driver behind illegal poisoning in Croatia is that local people wish to 'get rid of' alien or predator species, i.e., species such as Eurasian brown bear (*Ursus arctos arctos*), wild boar (*Sus scrofa*), golden jackal (*Canis aureus*), wolf, fox, and fallow deer (*Dama dama*). Human-wildlife conflict ensues with alien game species (mostly on the islands) and with predators on the mainland (mainly wolf, which is a protected species). Wolves were never introduced onto the islands, but the jackal was.

The islands of Croatia are well known for their rich biodiversity, and many endemic and relic species are represented there. Unfortunately, the hunting fraternity in Croatia see the presence of such species as an opportunity to make money from hunting tourism. On the islands, there are no native game species which would be attractive to hunters. Hence, hunters introduced animals which they considered appropriate, i.e., wild boar, fallow deer and brown bear, without regard for how these species may influence the balance within these well established ecosystems. Although poorly managed introductions of this type are considered unsound by many, Croatian hunters (and politicians) insist that introduced game are good for both the gene pool and for biodiversity and want to maintain existing populations. However, such species can cause damage to local assets and may affect the balance within the ecosystem. Likewise, human retaliation against such species can have wider implications. These species may prey on sheep, on native animals and plants, and may cause native species declines on the island ecosystems (where natural range and population size are limited, or species have already declined for other reasons). This type of conflict is a key factor on the Kvarner Islands in the northern Adriatic Sea. Here, the long-term survival of endangered griffon vultures is under threat as, for example, competition for food resources increases/continues, especially for dead sheep. Indirect impacts are also important, i.e., sheep herders put poisoned bait out to kill game animals introduced by hunters, which are then eaten by vultures and other animals (which the bait was not intended for).

In Croatia, hunting can take place in all areas except in towns and in highly protected zones. Animals are even hunted on private land, against the will of the owner. The hunting lobby is powerful, and often ignores laws and regulations regardless of their potential impact on ecosystems, other wildlife, domestic livestock, or the potential for damage to crops and forests. The area of Croatia that is probably most affected by the control/eradication of alien species is in the Primorsko-Goranska County. The County contains the Islands of Cres, Krk and Rab (Croatia's biggest islands). Many people here keep sheep in a traditional way (i.e., grazing extensively) because in the past, there were no predators on the islands. Attacks by game species on sheep occur on these islands and this is a relatively new problem, whereas on the mainland, they have been dealing with this problem since ancient times. Nowadays, hunters suggest that sheep grazed on the islands should be guarded and kept in stalls. If they are, herders could then perhaps claim compensation for any sheep killed by an introduced species. Farmers in turn claim that wild boar and bear kill lambs, and that they report this regularly, but action is not taken. Bears have also killed sheep on the Island of Krk, and they cause fear among residents and tourists (which is why people do not want this species on the island). All attempts to catch them alive, using baited cages, have so far failed. Hunting dogs also enter pasture areas, and chase, disturb, worry or even kill sheep.

Since sheep herders/farmers are not quickly or fully compensated for any losses/damage to their crops, individuals take matters into their own hands. They put down poisoned bait on available animal carcasses or on the remains of a slaughtered animal (usually a sheep) in an effort to rid the area of an unwanted species. In 2005 and 2006, local activists nature/environmental protection NGOs, and local sheep herder NGOs from the Islands of Krk and Cres led extensive and intensive anti-poisoning campaigns on the Kvarner Islands. While this made locals aware of the problem of unintentional poisoning, they continue to lay poisoned bait (albeit perhaps to a lesser extent). For example, they now tend to put the laced animal carcass under a brush, where it is supposedly less visible to griffon vultures.

The Eurasian griffon vulture is native to the Kvarner Islands, and its population status has almost certainly been affected by poisoning. The locally critically endangered breeding population here is estimated at only around 100 pairs. Many people live on these islands, hence information is more available. However, based on the number of cases reported in the media of sheep suspected to have been killed by wolves and people's complaints regarding this, the likelihood is that other areas such as Lika and Dalmatia (along the coast) are also affected by illegal poisoning. In this section, much of the information provided relates to research conducted in the Counties of Primorje and Gorski Kotar. To the best of the author's knowledge, little research has been undertaken in other Croatian regions.

In Lika (behind the Mountains of Velebit) locals experience conflict with wolves. People in their sixties and seventies often keep sheep and guard them while they graze. Wolves occasionally prey on these sheep, but government compensation for this loss is often slow in coming (it can take two years or longer to receive money for sheep lost due to wolves). The Ministry of Culture, Department for Nature Protection are well aware of the problems caused by such delays, but, they also state that money is simply not available. The author also suspects that the bear population, which is resident in Slovenia, Croatia, Bosnia and Herzegovina, is also being put at risk because of illegal poisoning in the Lika region. As scavengers, bears can also eat carcasses laced with poison.

The wolf is a near threatened species in Croatia. The 2010 wolf population in Croatia was estimated at 230 individuals in about 60 packs using a combination of telemetry data (which gives wolf pack territory size and the average number of wolves per pack) and distribution data (derived from wolf damage distribution data and snow track counts; Okovic 2010). The LIFE CRO WOLF project for wolf protection in Croatia ended in 2005. During the project, The Ministry of Culture – Department for Nature Protection and the State Institute for Nature Protection (which managed the project) received money to compensate people for damage to cattle and sheep. Now, government money alone is available for compensation. The State Institute for Nature Protection which conducted the LIFE project purchased electric fencing for sheep herders to keep wolves away from their livestock. They also donated Tornjak dogs to protect herds. Unfortunately, the author believes that many of the dogs have now been killed by illegal poisoning which was intended for the wolves.

The brown bear is also a near threatened species in Croatia. The 'Brown bear management plan for the Republic of Croatia' (Kocijan and Huber 2008) estimates that the brown bear population in Croatia is between 600 and 1000 individuals. Another report estimates there are around 1 000 bears. Data were obtained using molecular genetic methods, in this case DNA from fecal scat which was collected across three study areas (Kocijan and Huber 2008). This study also cautions that numbers must not be overestimated, as this may lead to an increase in any hunting quota, which would ultimately damage the bear population further.

Certain bird species are also considered as pests in Croatia (e.g., blackbirds (*Turdus merula*) and jays (*Garrulus glandarius*)). This seems to be a particular problem on the Islands of Krk and Cres, but certain birds are considered pests in other agricultural areas as well. As an example, Figures 5.19 and 5.20 show a sign that states 'beware poison' which was in a vineyard on the Istrian peninsula (above a plate showing a liquid poison). On Krk and Cres locals also apparently put carbofuran on cut tomatoes during the summer. Thirsty birds are attracted to the fresh tomatoes, and

Figures 5.19 and 5.20 The sign 'OTROV' (translation: POISON in Croatian) found over a plate filled with poisoned water in a vineyard on Istrian peninsula, near town of Kastelir. It was placed for birds which would eat grapes
Photos taken by Gordana Pavokovic

then die quickly after they eat them. Locals from the Island of Krk also practice deliberate secondary poisoning by collecting poisoned blackbirds and then putting them out as poison bait for foxes.

Bird species may also be poisoned by the improper use of rodenticides. Locals in Opatija, near Rijeka, for example, suggest they have noticed a significant decrease in the local sparrow population. House sparrows (*Passer domesticus*) readily eat wheat laced with rodenticide (such as that shown in Figure 5.18). For intentional poisoning, OP/CBs remain the poisons of choice however, since, as mentioned in Section 5.7.3, people can see their effects immediately/rapidly, they are inexpensive/ easy to buy and no control is exerted on their use.

Agricultural product misuse also occurs when there is a lack of expertise available to advise on correct practice, and to provide an inspection service to control approved use and pesticide sale. In remote areas such as the islands in Croatia, but also in southern Croatia, certain laws are perhaps not as strictly upheld/enforced as they are in other areas. For example, on the Island of Rab, officials demanded that an 'educated' individual should be employed in the shop selling agricultural chemicals, only after the griffon vulture poisoning incident of 2004.

Companion animals left behind by tourists are also poisoned. A common practice is unfortunately for people to abandon their pets before going on summer or winter ski holidays. There are only a few dog kennels, and many people consider these to be too expensive (i.e., around 7 EUR per day). There are laws against abandoning pets, but these are not enforced. Hence, after the summer, or in spring, numerous dogs and cats are abandoned and begin to beg for food, and many locals consider them a disturbance. Since animal shelters are in the hands of volunteers, and these often lack resources and space, many strays are poisoned, sometimes even by local people who simply dislike animals.

5.7.5 Nature protection and analytical capacity in Croatia

In Croatia, there are no governmental or NGO bodies that deal with wildlife incidents involving poisoning, whether this is with pesticides or anything else. Consequently, poisoning incidents often go unreported. A small proportion is picked up by newspapers, and some are investigated by nature protection inspectors (countryside rangers) or veterinarians, but these tend to result in private reports which are not divulged to a wider public/scientific audience. Numerous birds have been brought to the Recovery Centre (where the author worked) with clear symptoms of OP/CB poisoning. After examination, veterinarians usually confirm poisoning, ordinarily through the analysis of crop and stomach contents and/or tissue samples (e.g., liver and kidneys). However, signs of OP/CB poisoning, as confirmed by veterinarians, are often not considered important. The police and the Ministry of Culture and its Department for Nature Protection do not tend to take such incidents very seriously, and appear only to do so when the popular media get involved. Hence, although many wildlife poisoning incidents are noted/reported by local veterinarians, officially, illegal poisoning is not really recognised as a significant problem in wildlife management at all.

There exist two forensic laboratories in Croatia. One is private and the other is a police facility. There are also laboratories within some private veterinary practices, but these lack the necessary equipment to investigate suspected poisoning, i.e., GC/MS facilities. The Veterinary University of Zagreb has GC/MS and HPLC facilities, and could also perform histo-pathological analyses, but currently, there is no willingness to pay for wildlife necropsy in suspected poisoning cases. The private laboratory, which often focused on the investigation of incidents of wildlife poisoning (and where the griffon vultures from the Island of Rab were analysed), closed in 2009 due to a lack of funding for postmortem examination and tissue analyses. However, another private facility has recently been opened by the same individuals that managed the previous centre. The Centre for Forensic Research 'Ivan Vucetic', is the official police laboratory, and has a greater emphasis towards analysing human samples, for human forensic cases. Despite the fact that these facilities

exist, it actually remains very difficult to gather the necessary evidence required to prove an illegal wildlife poisoning case. One key issue regards the maintenance of 'chain of custody' (i.e., a legal record of sample handling and transport between the point at which the sample is collected and that at which forensic analysis is completed) since there is no clarity in the system regarding who should collect then transport samples to the laboratory. There is also a lack of human capacity (i.e., of experts to determine animal poisoning has occurred), and of legal procedures for investigating poisoning incidents.

Another issue is the perception of wildlife poisoning in some laboratories. For example, at the Veterinary Institute (Veterinary University of Zagreb), carcasses are often deemed too decomposed to investigate. Dead birds, submitted for analysis, are often rejected by the Institute on this basis. This seems unusual when poisoning is suspected, since a poison can be clearly detected in a highly decomposed carcass given the correct procedures. Numerous laboratories within Europe are able to determine the presence of poisons in carcasses that are highly decomposed. One colleague stated (off the record), that when there is suspicion of poisoning, it is normal practice to say that the carcass is too decomposed. If poison were confirmed, scientists might be called as expert witnesses to testify in court, and they could then 'lose' time, for which they would not be compensated.

Without official recognition that wildlife poisoning is a problem, it is difficult to estimate the number of incidents linked with carbofuran or other compounds. State institutions involved in biodiversity conservation do not currently collect data on poisoning incidents, and there is no sampling protocol in place for animals suspected to have been poisoned. There is legal protection, in the sense that laws to protect animals exist, however, in reality, if one discovers dead eagles in the environment (for example), there is no mechanism in place in terms of who to contact, who should collect the carcass, where to send the samples for analysis, and importantly, who will seek out the culprit? Even if a culprit is identified, the prevailing legal process seems flawed. Within Croatia, there are regular cases regarding corruption at the government/judicial level, hence, wildlife poisoning (for many) can appear to be a minor problem. When poisoning incidents occur, the most common reaction is to avoid them, i.e., the police will say that they are not in charge of wildlife crime, and government inspectors of all kinds will try to hand off a case to someone else.

5.7.6 Recommended steps to address the current threat posed by carbofuran

In a country where the existence of illegal poisoning must first be acknowledged within government, there remains a need for a concerted campaign. At the moment, it is almost impossible to take any action against perpetrators. There is no conservation organisation dedicated to this issue, and authorities do not currently have an interest in this problem. While the problem should be solved at the government level, there is a need to establish coordination between NGOs and the government, and to present government bodies with sound recommendations as to the methods necessary for effective action.

One important objective should be to develop and implement an awareness program. The aim should be to increase knowledge regarding the repercussions of wildlife poisoning on ecosystems, and this process should take into account the attitudes of Croatian people. This programme must include stakeholder consultation, should model how to control illicit activities, model how ecosystems interact, monitor results/outcomes, and review systems on an ongoing basis. There is also a need to establish measures by which Croatia can regulate the production, distribution, selling and transportation of poisons such as carbofuran. The aim must be to prevent and ultimately stop deliberate and illegal use.

All measures conducted by an 'anti-poisoning campaign' should be based on the overall objective of dissuading those who are considering the use of poisons. The campaign must establish mechanisms regarding long-term action against illegal poisoning. Conservation and the stabilisation of Croatian endangered species must be prioritised, and measures should focus on populations in jeopardy due to poisoning (i.e., vultures). Habitat loss and fragmentation are also major threats to large

carnivores in Croatia, as is the loss of natural prey species. Much of this is due to poaching, another problem which is not officially recognised. Such issues need to be addressed at the same time.

A scheme must be created so that illegal poisoning incidents will be properly investigated. Incidents shown to involve pesticides should be distinguished by category, i.e., misuse by carelessness, accidental or wilful failure to adhere to correct practice, or abuse of a pesticide in the form of deliberate/illegal attempts to poison animals. The scheme should contain protocols that enable people to submit carcasses and poisoned baits for laboratory analyses. There is also a need to establish an official centre for the necropsy, histo-pathological and toxicological analyses of suspected poisoned animals.

Collaboration among Croatian ministries, institutions, organisations and NGOs is also required. Those who work in nature conservation, animal welfare, hunting, the production and distribution of pesticides, as well as those who work with the problem of animal poisoning should participate in the 'anti-poisoning campaign'. On Croatian islands, there is a need to mitigate against damage caused by introduced species, in order to protect the traditional way of life there, and to protect biodiversity. State assistance should be available to allow alien species removal.

A long-term, multi-faceted approach, that is organised and systematic is required if Croatia is to address the problem of illegal wildlife poisoning. Without such a programme, Croatia's threatened species will be devastated, its ecosystems degraded, and traditional livelihoods could be swept away.

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6 Perspectives on wildlife poisoning by carbofuran in the United Kingdom and Republic of Ireland – with a particular focus on Scotland

6.1 An overview of the registration and withdrawal of carbofuran products

The United Kingdom (UK; comprised of England, Wales, Scotland and Northern Ireland) is a Member State of the European Union (EU), the subject of the previous chapter. The Republic of Ireland (ROI; distinct from Northern Ireland) is also an EU Member State. Although many readers will have some familiarity with Ireland's political history, not all may be aware that the ROI is a distinct EU Member State, and not part of the UK (see Figure 6.1).

Products containing carbofuran were approved for use in England, Scotland, Wales and Northern Ireland until 2001, when approval expired (Chemicals Regulation Directorate, personal communication 2011). In contrast, carbofuran products were revoked in the ROI on 12 December 2007. A grace period was also permitted whereby any remaining stocks could still be used until 12 December 2008 (following Directive 2007/416/EC; European Commission, and refer to Chapter 5). Tables 6.1 and 6.2 list the products that were approved in the UK and the ROI, respectively, in order of approval.

These tables also show that carbofuran products were legally available in the UK between 1987 and 2001, and in the ROI between 1985 and 2008, respectively. Their 'illegal' use, however, remained in evidence up until as late as 2010, as indicated by the recent poisoning incidents discussed within this chapter. Chapter 2 highlighted how little active ingredient is required to (fatally) poison a bird. Hence, even a small reserve stock could continue to be used illegally for a potentially very lengthy period.

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Figure 6.1 Map delineating the United Kingdom and the Republic of Ireland

Table 6.1 Registration period for products containing carbofuran in the United Kingdom

Product name	Manufacturer	Approval date	Expiration date
Yaltox	Bayer plc	12/01/1987	12/31/2001
Throttle	Bayer plc	11/05/1990	12/31/2001
Nex	Sipcam UK	01/28/1991	12/31/2001
Rampart	Sipcam UK	01/28/1991	12/31/2001
Barclay Carbosect	Barclay Chemicals Manufacturing Ltd	07/17/1991	2/29/2000
Stefes Carbofuran	Stefes Plant Protection Ltd	03/24/1994	02/29/2000
Yaltox	Bayer plc	05/04/2001	12/31/2001
Carbosip 5G	Dart Brothers	04/10/2001	12/31/2001
Carbosip 5G	Dart Brothers Farms Ltd	01/11/2001	12/31/2001

Information obtained from the Chemicals Regulation Directorate, United Kingdom, 2011

Table 6.2 Registration period for products containing carbofuran in the Republic of Ireland

Product Name	Manufacturer	Approval Date	Revocation date
Barclay Carbosect 5G	Barclay Chemicals Manufacturing Ltd	02/12/1985	12/12/2007
Carbosip	Dart Brothers	02/12/1985	12/12/2007
Hycarbo	Hygeia Chemicals Ltd	02/12/1985	12/12/2007
Yaltox	Bayer plc	02/12/1985	12/12/2007
Yaltox Combi	Bayer plc	02/12/1985	25/07/2003
Yaltox HG	Bayer plc	02/12/1985	01/01/2001
Croplink Furan 5G	Croplink Ire Ltd	23/03/2001	23/03/2002
Croplink Furan 5G		08/04/2002	08/04/2003
Croplink Furan 5G		19/03/2003	09/03/2004
Croplink Furan 5G		25/02/2004	25/02/2005
Croplink Furan 5G		29/05/2007	12/12/2007

Information obtained from the Pesticide Control Service, Department of Agriculture, Fisheries and Food, Republic of Ireland, 2011

6.2 An overview of human-wildlife conflicts in the UK and ROI

The predominant 'human-wildlife conflict' in this part of the world essentially stems from historic/current farming and hunting practices. Whilst the practice of hunting game birds, such as common pheasant (*Phasianus colchicus*), is undertaken in many European countries (see Chapter 5), hunting for red grouse in particular (*Lagopus lagopus scoticus)* and managing the land to encourage this species is rather unique to the United Kingdom. Game bird hunting is a well established tradition in the UK and brings significant economic benefit to the communities involved in such 'country sports'. Driven grouse shooting dates back to the advent of efficient breech loading guns on sporting estates in the early Victorian era (from the 1830s to 1900). The practice of 'driving' grouse involves flushing (i.e., 'beating') the birds towards hunters, who stand/hide and wait in enclosures known as butts. The 'beaters' create a human line (some distance from the hunters) and walk in that line whilst waving flags to flush the grouse towards the hunters.

The majority of UK driven grouse shooting is conducted in northern England and Scotland, and these areas are thus the focus of Section 6.3. As discussed in this section, birds of prey have been historically targeted on sporting estates because of the perception that they pose a significant threat to game bird species, and therefore could compromise hunting activities/profit. Unfortunately this view has often been seen to be at odds with other equally economically important and valid interests such as ecotourism, birdwatching (i.e., ornithology), and sightseeing, all of which rely on the preservation and sustainable management of diverse environmental resources. Conflict tends to occur when such resources (birds of prey) are seen as a 'pest' or as having the potential to harm the interests of landowners and the game industry.

Elsewhere, in some UK/ROI farming communities, poisoned bait is unfortunately still being used to control foxes, crows and birds of prey, primarily during the lambing season, especially in Wales and various parts of the ROI. The practice of (legal) baiting was only outlawed in the ROI in 2010. Likewise, despite the 2008 withdrawal of carbofuran in ROI, samples have still tested positive for residues of several compounds used as poisons, including carbofuran (see http://www.goldeneagle.ie/news_viewnews.php?x=8&z=132&f=5&news_id=11&start=0&highlight=sasa). In several instances, birds which have been donated by other countries (e.g., Norway [sea eagles],

Scotland [golden eagles] and Wales [red kites]) as part of collaborative re-introduction efforts, have also been found to have been poisoned (http://blog.norway.com/2010/05/12/norwegian-eagles-are-poisoned-in-ireland/), which puts further strain on the logistics and public relations effort being used to further such important collaborative initiatives.

The following sections provide three quite distinct but equally valid stances (with an emphasis on Scotland), on the current situation. The first is offered from the viewpoint of a scientist and raptor conservation biologist who, along with a number of colleagues, has been involved with various re-introduction programmes, including population-level and individual bird monitoring over time. The second contribution represents the position of landowners in Scotland. The third author works in a Scottish government laboratory which monitors the impact of pesticide use on wildlife, domestic animals, livestock and honeybees and works to unite the various stakeholders. This author details how the abuse of carbofuran is currently monitored, and presents information regarding the mitigative measures that are now underway.

6.3 The effect of carbofuran poisoning and other illegal persecution methods on raptor populations in Scotland

Ruth E. Tingay

Member of the Scottish Raptor Study Group and the President of the Raptor Research Foundation

Raptors in the UK have been subjected to poisoning and other methods of persecution for over 150 years (e.g., Alison 1856). Alongside the popularity of game bird hunting, especially in the late 1800s and early 1900s, (and particularly red grouse hunting, a sporting tradition peculiar to the UK), most raptor species were considered to be 'vermin', and a significant threat to game bird survival. As such, legal predator control was permitted during this period, and thus landowners who were keen to preserve artificially high numbers of game birds encouraged their gamekeepers to eradicate as many raptors as possible (Anonymous 2000). Other groups were also involved in legal raptor persecution, either directly (e.g., sheep farmers, skin collectors – during the Victorian era it was fashionable to display stuffed birds as decorative conversation pieces in drawing rooms and parlours; Mearns and Mearns 1998) or indirectly (e.g., egg collectors, see also Section 5.3.1).

The most direct methods used for legal persecution included poisoning, trapping, shooting and nest destruction. Their combined effect resulted in dire consequences for many raptor populations. By the early 1900s, several species had become extinct in Scotland including the white-tailed sea eagle (*Haliaeetus albicilla*; Love 1983), goshawk (*Accipiter gentilis*; Marquiss and Newton 1982), red kite (*Milvus milvus*; Evans, Dennis, Orr-Ewing et al. 1997) and osprey (*Pandion haliaetus*; Brown and Waterston 1962). Other species in Scotland managed to avoid extinction, but suffered severe range contraction as a direct result of persecution, including the hen harrier (*Circus cyaneus*; Watson 1977), peregrine falcon (*Falco peregrinus*; Ratcliffe 1993) and the golden eagle (*Aquila chrysaetos*; Watson 1997).

Poisoning, specifically the setting of poison baits in the open, was first outlawed by the Protection of Animals (Scotland) Act in 1912, although this legislation did not include legal protection for birds. The legal persecution of raptors was not prohibited until the introduction of the Protection of Birds Act in 1954. Following a change in society's perception of raptors over the following 50 years, several raptor recovery projects took place in Scotland, i.e., white-tailed sea eagle re-introduction (Love 1983) and red kite re-introduction (Evans, Dennis, Orr-Ewing et al. 1997). Further legislation to protect raptors was also introduced during this period, including a complex array of Scottish,

UK and European-specific laws. These afforded most Scottish raptor species the high level of legal protection we now have today. However, such legal protection is only effective if it is properly policed and enforced with adequate resources. The remainder of this section discusses the results of peer-reviewed studies which have demonstrated that illegal raptor persecution is both widespread and relentless even in the twenty-first century in Scotland. It is affecting the recovery of several important raptor populations. Poisoning, and particularly the use of baits laced with carbofuran on grouse moors, is central to this issue.

Of all the methods used to illegally persecute raptors in Scotland, poisoning may be considered the greatest actual or potential threat. In contrast to shooting and trapping, which requires a sustained effort to produce a limited return, poisoning can have a substantial impact with minimal effort. Poisoned bait continues to be lethal over a period of days, weeks or months, and can kill multiple victims without further effort on the part of the culprit (RSPB 2009a). The raptors which are most vulnerable to poisoning are those that regularly use scavenging as a foraging technique. In particular, these are the common buzzard (*Buteo buteo*), red kite, golden eagle and white-tailed sea eagle. Table 6.3 shows the number of confirmed raptor poisonings reported in Scotland between 1998 and 2010. Of 378 confirmed cases, 261 (69%) were attributable to carbofuran. Carbofuran was withdrawn as a legitimate agricultural pesticide in December 2001, yet, despite it being a criminal offence to even possess the substance, it is the 'poison of choice' in the vast majority of recently-recorded incidents (RSPB 2009a). Alpha-chloralose, aldicarb and mevinphos have also been used, although they do seem to be less popular (RSPB 2009a).

These poisoning figures are considered to be conservative estimates at best (e.g., RSPB 2009a) because persecution obviously often takes place on remote grouse moors where witnesses are absent or limited. A poisoned victim usually tends to be discovered by chance, for example by a passing hill-walker. However, using data from the ongoing Scottish Raptor Monitoring Scheme (Wernham, Etheridge, Holling et al. 2008), population modeling can be used to infer the true extent of the impact of persecution on raptor populations. Recent studies have demonstrated unequivocally that the populations of golden eagles (Whitfield, Fielding, McLeod et al. 2004; 2008), hen harriers (Etheridge, Summers and Green 1997; Fielding, Haworth, Whitfield et al. 2011) goshawks (Marquiss, Petty, Anderson et al. 2003), peregrines (Hardey, Rollie and Stirling-Aird 2003) and red kites (Smart, Amar, Sim et al. 2010) are all severely constrained in parts of Scotland, as a direct result of illegal persecution on shooting estates.

Despite these peer-reviewed scientific studies, that clearly demonstrate the link between illegal raptor persecution and game-management, the game-shooting industry unfortunately continues to deny direct responsibility, and claims that gamekeepers are being unfairly blamed (e.g., Dracup 2009, SRPBA 2011). However, data collected on the occupations of the 21 people convicted for raptor persecution offences in Scotland between 2003 and 2008 clearly show that 85% were indeed gamekeepers, and the remainder were (at 5% each): pigeon racers, farmers and pest controllers (RSPB 2009a). The shooting industry also often claims that the extent of raptor persecution is exaggerated, and that 'just a few rogues' are responsible (e.g., Randall and Owen 2007). However, according to Raptor Persecution Scotland (2010a), wildlife crime incidents have been reported on 77 different estates between 1990 and 2010, which seems to illustrate quite clearly that illegal persecution is considerably more widespread. Evidence of the potential widespread effect that such persecution may be causing is further indicated by recent data which suggest an estimated 2 600 hen harriers (approximately two-thirds of the predicted population) are 'missing' from apparently suitable breeding habitat across Scotland. There is a clear relationship between areas where most hen harriers are absent, and land managed for driven grouse shooting (Fielding, Haworth, Whitfield et al. 2011).

Unfortunately, while the game shooting industry fails somewhat to effectively tackle the issue of illegal poisoning, it also has sometimes made some rather 'outlandish' claims which do not help to create links of trust between conservationists/scientists, and the shooting industry.

Table 6.3 Confirmed raptor poisonings in Scotland 1998[a]–2010

Year	Red Kite	Buzzard	Goshawk	Peregrine	Hen Harrier	Tawny Owl	Sparrow- hawk	Golden Eagle	White-tailed Sea Eagle	Total
1998	4 (1)	22 (15)	0	2 (2)	1 (1)	0	0	2 (2)	0	31 (21)
1999	4	10 (2)	0	0	0	0	0	3 (3)	0	17 (5)
2000	2 (1)	14 (10)	0	1	0	1 (1)	2	2 (1)	0	22 (13)
2001	11 (9)	13 (4)	0	0	0	1	0	1 (1)	0	26 (14)
2002	2	13 (11)	0	1	0	0	1	2 (2)	2	21 (13)
2003	10 (6)	24 (22)	0	3 (3)	0	0	2 (2)	0	1 (1)	40 (34)
2004	4 (2)	39 (35)	1 (1)	3 (2)	0	1	1	0	0	49 (40)
2005	2 (1)	14 (12)	0	0	0	0	0	1 (1)	0	17 (14)
2006	5 (5)	24 (22)	0	1 (1)	0	1	1	2 (2)	0	34 (30)
2007	10 (10)	12 (11)	0	4 (3)	0	0	0	1 (1)	0	27 (25)
2008	3 (2)	16 (9)	0	0	0	0	2	0	1 (1)	22 (12)
2009	5 (3)	20 (11)	0	0	0	1	0	2 (2)	1 (1)	29 (17)
2010	16 (5)	17 (13)	0	2	0	0	3 (1)	4 (3)	1 (1)	43 (23)
Total	78 (45)	238 (177)	1 (1)	17 (11)	1 (1)	5 (1)	12 (3)	20 (18)	6 (4)	378 (261)

Numbers in parentheses indicate carbofuran incidents
Data sourced from SASA, 2011
[a]Data prior to 1998 are not available in the public domain

For example, in certain cases, the suggestion has been that anti-hunting groups have 'planted' poisoned carcasses on sporting estates as part of a campaign against gamekeepers (e.g., Raptor Persecution Scotland 2010b; 2010c). This rather bizarre (and unsubstantiated) claim was tested in 2007, when a golden eagle was found dead under her nest on a sporting estate in the Scottish Borders. The bird was one half of the only breeding pair remaining in the Borders, and had been poisoned by carbofuran. The suggestion was (according to the Chairman of the Scottish Gamekeeper's Association) that the eagle had been planted on the estate to coincide with the beginning of the annual grouse-shooting season on 12 August as a publicity stunt to tarnish the reputation of grouse-shooters (A. Hogg, personal communication 2007). The suggestion was that the eagle in question was from elsewhere in Scotland (and was a historically poisoned, archived specimen) and had been brought to the site by those opposed to the hunting activity. However, this eagle had previously been DNA-sampled at her nest (during the two previous breeding seasons) as part of a national study on golden eagle population dynamics (Tingay, Whitfield and McGrady 2008). DNA obtained from the dead eagle was compared with the DNA profile on record for the resident female, and it was indeed an identical match (Tingay, unpublished data).

In May 2010, the Scottish Rural Properties and Business Association (SRPBA – a group representing landowners) launched a public relations exercise following the high-profile discovery during that month of three golden eagles (two poisoned with carbofuran, one with aldicarb) on the Skibo Castle sporting estate in northern Scotland. The SRPBA, and other game-shooting interested bodies, were responding to public concern about raptor persecution on Scottish sporting estates. The response was also prompted by an RSPB petition calling for the government to take stronger action against the perpetrators of such crimes (which had been released earlier in the year, and which had been signed by 210 567 members of the public). Over 200 prominent landowners then signed a letter to the Scottish Environment Minister, condemning raptor poisoning and calling for the 'full weight of the law' to be brought down on those who commit such crimes'.

Unfortunately, the inherent sincerity (and therefore credibility) of the letter, or at least some of its signatories, was subsequently questioned. For instance, wildlife crimes had previously been reported on some of the estates represented i.e., 23 estates (Raptor Persecution Scotland 2010d). In addition, just one month later, multiple dead raptors and poisoned baits were discovered on Moy Estate in the Scottish Highlands despite the fact that the owner was also a signatory to the SRPBA letter (Raptor Persecution Scotland 2010e). While the signatories/estate owners may well condemn such persecution personally, they are therefore evidently failing to prevent such incidences occurring on their own managed land, often at the hand of their own supposedly trusted employees.

The investigation and prosecution of raptor persecution incidents in Scotland is also often heavily hampered either by a lack of resources or by procedural difficulties. Recently, evidence has suggested that the Scottish police are not meeting their full statutory duty to investigate wildlife crime (i.e., they are not fully investigating reported incidents of alleged persecution; RSPB 2009b; Raptor Persecution Scotland 2010f). Where convictions have been secured, the punishment is typically a derisory fine, community service, or a formal 'admonishment' (RSPB 2009a). Harsher penalties are certainly available following the enactment of the 2007 Criminal Proceedings (Reform) (Scotland) Act. Fines of up to £10 000 can be levied, and/or each offence is punishable by a year's prison sentence, but to date, such sentencing has not been applied. There is therefore little deterrent prevailing in the system, although recently there have been a few cases where substantial farming subsidies have been withdrawn from estates under European Cross Compliance legislation (RSPB 2009a).

Although the issue of illegal raptor poisoning is high on the Scottish political agenda in 2011, there are also still some politicians who do not fully accept that there is a significant problem in Scotland. Recently (in December 2010), a Minister stated in Parliament that he considered raptor persecution to be a 'part real – part imaginary crime' (Raptor Persecution Scotland 2010g). Again (in the author's view), such statements suggest that Victorian attitudes still persist in the UK, and that

the shooting industry is acting as though it is currently rather incapable of responsible, sustainable self-regulation. Within Scotland there remains an urgent need to improve the effective enforcement of the current legislation. Given the persistently high level of illegal raptor poisoning in Scotland, it is perhaps time for the introduction of mandatory custodial sentences for offenders, so that judicial discretion is limited by the law. Custodial sentences, although not mandatory, were indeed successfully introduced for egg-collecting offences in Scotland in 2003, and this has led to a dramatic reduction in illegal egg-collecting incidents (RSPB 2009b). In addition, a licensing scheme for sporting estates should be given serious consideration. Specifically, where persistent raptor poisoning events occur on an estate, its shooting license should be withdrawn for a period of time commensurate with the seriousness of the offence. An estate-licensing scheme was proposed during the recent development of the Wildlife and Natural Environment (Scotland) Act 2011; however, the proposal was rejected by the Scottish Parliament.

In 1998, the Secretary of State at the time, Donald Dewar, described the level of raptor persecution in Scotland as a 'national disgrace'. Thirteen years later, this still remains the case, and further action to prevent it from continuing is certainly long overdue.

6.4 A landowner's perspective on wildlife poisoning in Scotland

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Regrettably, in Scotland, the problem of illegal poisoning has not yet been eradicated, although good progress has been made. Around 20 to 25 illegally poisoned bird of prey cases are still reported each year (some involving the illegal use of carbofuran), and the land management industry is determined to bring this number down to zero as soon as possible. Not only is such poisoning indiscriminate (e.g., household pets or children could also be exposed), but it affects rare species such as golden eagles, which land managers see as being under their responsibility. The ensuing publicity is also highly damaging to an industry which does so much to look after Scotland's wildlife and landscapes. For all these reasons, the organisations which represent land managers and sporting interests are absolutely unequivocal in their condemnation of wildlife poisoning.

Addressing this area of criminality requires factual evidence and good data. This is why the Scottish Rural Property & Business Association (SRPBA, which represents landowners and estates across Scotland) has been working with the RSPB, the Scottish Government and Science and Advice for Scottish Agriculture (SASA, see Section 6.5) since 2008 to produce evidence of the true scale of confirmed illegal poisoning incidents in this country. Focusing on birds of prey, these confirmed illegal poisoning figures are agreed between the main partners each year then launched publicly as part of our joint efforts to eradicate this problem. The official data for 2010 was published in March 2011, and it reported 22 incidents of illegal poisoning in Scotland, which resulted in 28 dead birds of prey. Although this represents an increase of one bird in comparison to the 2009 figures, we have observed an overall downward trend since a high of 35 in 2006 (http://www.scotland.gov.uk/Topics/Environment/Wildlife-Habitats/paw-scotland/types-of-crime/crimes-against-birds/Poisoninghotspotmaps2010/2011). For the first time this year, in 2011, the partners in this process included members of the Scottish Raptor Crime Priority Group (Scottish Raptor Study Groups, Scottish Gamekeepers Association, British Association for Shooting and Conservation as well as the Police) under the umbrella of the Partnership Against Wildlife Crime Scotland (PAWS). This year, all parties were involved in the process of statistical analysis and mapping, and, all agreed

to report *these figures* as the 'official statistics' in communications on this issue (in contrast, for example, to the 'unofficial RSPB' data cited in Section 6.3).

The continual sensationalism and exaggeration of the problem is a significant impediment to progress. Looking only at the 22 incidents of illegal poisoning of birds of prey in 2010, the allegations and rumours that were circulated developed an almost hysterical pitch at times, largely due to what we feel stemmed from a lack of hard information. The public should (but does not often) know that many investigations of these types of offences do not lead to charges being brought, and that this is usually due to a lack of evidence. While such unresolved cases are rarely closed, their status does not tend to reach the public domain either. Instead, the information remains firmly in police hands and details of the incident are not divulged even to the landowner. This situation results in both unhelpful and unfair speculation by those having their own particular agendas (i.e., those opposed to game shooting or estate land ownership), and is usually based on partial leaked information.

A good example of how damaging such speculation/perceptions can be involved a dead golden eagle found with carbofuran in its throat in Peebleshire (2008). This discovery coincided very closely with the 12 August opening date of the grouse shooting season in Scotland and (unsurprisingly, to us) the media and others (e.g., conservation and animal welfare groups) immediately jumped to the conclusion that the owner of the land where the bird was found was responsible for its death. This incident (and the sensational photographs which showed policemen holding up the dead eagle in various dramatic poses) was used to generate substantial anti-grouse shooting publicity to damage the normally good publicity in the media that accompanies the opening of the grouse shooting season on 12 August every year. This occasion is unique to Scotland and worthy of celebration. However, nothing more came of the police investigation or of the case. It later transpired that the land involved was not in fact a managed grouse moor and that the landowner had known the eagles were on his land and done his best to protect them for the last decade. By the following spring, eagles were breeding there again and the police officer who had led the investigation had left the force. The fine details of what actually transpired during this case remain unknown but despite final official recognition that the landowner was not involved in any way in this incident, we feel that the ensuing publicity had already cast an indelible mark on landowners.

In my view (and those of many landowners and other industry organisations), websites such as 'Raptor Persecution Scotland' (see http://raptorpersecutionscotland.wordpress.com/), which allow their contributors and editors to anonymously make personal attacks on individuals without fear of reprisal or any hard facts, fuel and increase such speculation. Indeed much of the 'information' provided on this site is well out of date. Such websites publish comments regarding owners of land where dead birds have allegedly been found, or where bad practice has been suggested, but they do not substantiate such allegations with any proper evidence, nor do they offer the landowner the chance for rebuttal. Irresponsible/inflammatory coverage of ongoing police cases and investigations on this website has also raised significant concern within the Scottish Police and Scottish Government. As a result of all these factors, my colleagues and myself deem this particular website to be speculative, subjective and fundamentally prejudiced. Indeed, the existence of such websites has bred antipathy between land managers and raptor enthusiasts, which has further exacerbated the problem, and undermines the positive efforts underway to resolve these issues.

Unfortunately, 'animal rights extremists' who seek a complete end to game shooting and sporting estates, and land reformists, who wish to see large private landholdings, such as private country estates, broken up and redistributed, ignore all the very good work that landowners on estates do day in and day out to deliver public goods such as landscape, habitat and wildlife management. For example, the Cambridge-based Public and Corporate Economic Consultants reported that game shooting in Scotland was worth over £240m per annum to the Scottish economy and supported 58 000 paid jobs (see The Economic and Environmental Impact of Sporting Shooting – PACEC Report 2006, www.shootingfacts.co.uk). The report also showed that the practices used to manage land

for shooting, spanning 4.4 of Scotland's 7.8 million hectares, offer major secondary benefits to biodiversity and deliver the equivalent of 2 000 full-time conservation jobs. Private landowners also collectively invest over £43m each year on habitat improvement (including that of birds of prey) and wildlife management ventures.

There is also increasing concern among land managers regarding recent research which seeks, through population modelling, to demonstrate that the populations of certain birds of prey are below the levels they *could* be and that persecution is the reason for this. A recent example of this was the joint hen harrier conservation framework report published in February 2011 (Fielding, Haworth, Whitfield et al. 2011). SRPBA and other industry organisations (most notably The Game and Wildlife Conservation Trust, a respected UK scientific organisation) identified a number of fundamental concerns with this report and raised some very specific scientific failings and flaws within it. These failings and flaws seriously undermined the validity of some of the report's key findings. What was and remains more concerning to the SRPBA, given these questionable conclusions, was the manipulation of the publication date in an attempt to influence a piece of legislation (i.e., the Wildlife and Natural Environment Bill) that was moving through the Scottish Parliament. The report was being used to try and restrict game shooting on estates in Scotland. In the end, the Scottish Parliament did not support these damaging proposals and we very much welcomed this balanced view. Scientists, whatever they specialise in, should be impartial and avoid getting involved in the realm of speculation, otherwise their science is surely questionable.

It is noteworthy that a significant amount of 'legal' poisons are still used in rodent and pest control each year, and these cause many more untargeted accidental bird of prey deaths than illegal 'abuse' does. The illegal use of poison is in decline, even if the speculation about it is not. Recent initiatives to enable farmers and land managers to hand in 'out of date' chemicals for free disposal have been very well received. Such schemes should be further expanded within Scotland to facilitate the submission of now illegal substances like carbofuran, so that remaining 'bottles in sheds' can be removed from the system, along with any temptation to use them. There have been instances where an estate employee has tried to hand in such now illegal substances to law enforcement offices and has been told to take it away. We need a better system than that. The SRPBA has been campaigning for such amnesty schemes in Scotland since 2007. A calm and methodical approach, both by police and government, in partnership with the game shooting and farming industry, is needed to finally resolve this issue.

However, at some point, the underlying causes of crime have to be examined and explored too. If some illegal poisoning in Scotland continues today, we must ask why this is the case, especially given the criminal penalties which exist. Why would people continue to take the risk? The answer to this may lie in the fact that although the existing legislation in Scotland, as transposed from the relevant EU Directives, does indeed allow for the legal control of wild birds where they are inflicting serious damage, in practice the process is not working. It works in other land management sectors where the control of wild birds is routinely sanctioned by licence to prevent serious damage to agriculture or fisheries, for example licenses are regularly issued to farmers to shoot ravens to prevent serious damage to their livestock, but not for game shooting. This imbalanced approach also needs to be addressed as part of the solution. What Scotland needs now is a proper Dispute Resolution Process in this area where those with open minds and a real desire to solve this intractable set of issues can work together to find the appropriate solutions.

In summary, we believe that only a proper evidenced-based approach to the problem will effectively eradicate the illegal use of poisons such as carbofuran. If the facts delimit the problem, we can then address the causes of crime in these areas in a focused manner. This should be supported by an official Dispute Resolution Process, which will be focused on identifying long-term solutions, including an appropriate range of legal management tools. SRPBA sits on the Board of the Partnership Against Wildlife Crime in Scotland and our members are active in each of the local groups of PAW, so there should be no doubt about the sincerity of our members in this area. We believe that working together, in partnership, is the best way to find solutions to this problem. This is clearly illustrated by the fact that, in 2010, no cases of illegal poisoning were reported in the

Grampian area of Scotland (where SRPBA are very actively involved in the local PAW group and our members' estates, mostly with game shooting interests are working in partnership in the local Grampian Raptor Watch project). This shows the way forward; working in partnership using a sound evidence base, not polarised views and media hype.

The land management industry particularly applauds the role of high quality science in finally stamping out this problem. Laboratories such as SASA conduct the impartial analysis needed to ensure that speculation does not run rampant.

6.5 Monitoring carbofuran abuse in Scotland

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6.5.1 Introduction

In July of 1988, a most peculiar pigeon carcass was discovered on a boundary between a field of cereal and woodland in a small village located towards the east coast of Scotland. The carcass had been cut open, and the exposed flesh was covered with a blue granular substance (Figure 6.2a). It was submitted to SASA for chemical analysis where it was identified as the first reported case of

Figure 6.2a Pigeon carcass baited with blue granules found in 1998 in a small village on the east coast of Scotland

Figure 6.2b Rabbit carcass baited with blue granules and fixed to the ground with a wire, found in 2009 towards the west coast of Scotland

carbofuran abuse in Scotland. Twenty-one years later, in March 2009, a rabbit carcass was discovered in a field towards the west coast of Scotland (Figure 6.2b). This carcass was fixed to the ground by a metal wire. Once again the carcass had been opened, and a blue granular substance covered the exposed flesh. Analysis carried out by SASA confirmed that the blue substance was again carbofuran.

These two incidents involving poisonous bait confirm that the illegal practice of animal poisoning in Scotland persists. The Chemistry Branch of SASA has operated the Wildlife Incident Investigation Scheme (1) (WIIS – Scotland) on behalf of the Scottish Government since the mid 1970s. The scheme, conceived to monitor any impact on wildlife, domestic animals, livestock and beneficial insects (e.g., honeybees) following legitimate, legal use of agricultural chemicals, operates in parallel with the provision of analytical chemistry support for wildlife crime investigations and enforcement of a variety of legislation.

Ultimately, WIIS reveals exposure following 'approved use', 'misuse', 'abuse' and 'unspecified use' of pesticides and biocides, which can invoke investigation and enforcement of various legislation. Operation of the WIIS is funded via a shared government and (pesticide) industry funding model administered by the UK Health and Safety Executive's Chemicals Regulation Directorate (2).

6.5.2 The impact of carbofuran abuse in Scotland

Though SASA has routinely tested specimens for a wide range of chemicals under the scheme, the most prevalent substances encountered in suspected poisoning incidents in Scotland are strychnine, chloralose, mevinphos and carbofuran. Residues of these four chemicals have been detected in 92% of all incidents categorised by WIIS-Scotland as 'abuse' (i.e., the deliberate and illegal attempt to poison animals). Figure 6.3 depicts the annual detection frequency of each of these chemicals in WIIS-Scotland incidents since measurements and records began in the early/mid 1970s.

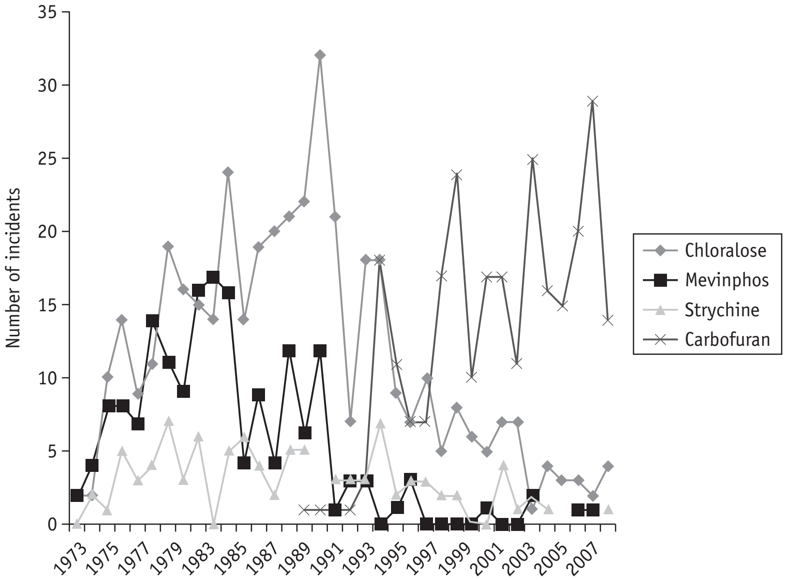

Figure 6.3 Number of incidents (four year rolling average) in which the four most abused chemicals have been detected in the WIIS-Scotland (1973–2008)

The data suggest that carbofuran has emerged as the poison of choice in Scotland, and this is regardless of the fact that it is illegal to use or even possess products containing this active ingredient. Carbofuran was banned in the UK in 2001 (refer to Section 6.1), and was included in the Possession of Pesticides (Scotland) Order 2005 (3). By the late 1980s and early 1990s the incidence of carbofuran-related mortality began to climb, while that of the other three compounds mentioned showed a decreasing trend.

It is difficult to say why carbofuran use appears to have increased substantially. It is possible that an increase in publicity has heightened awareness of its use to poison wildlife species, which in turn has increased the number of incidents reported or carcasses submitted. Incident submissions are undoubtedly biased towards birds of prey, which may reflect their vulnerability as scavengers or the fact that they are specifically targeted. However, the variety of vertebrate animals in which residues of carbofuran have been detected indicates that the setting of baits laced with the deadly poison is indiscriminate and any scavenger, predatory or curious animal is vulnerable.

In principle, more birds of prey are submitted than other species because there are several groups/individuals/laws dedicated to their welfare as opposed to mammals (e.g., foxes) and other birds (e.g., crows and ravens). SASA also frequently deal with a high number of 'companion animal' poisonings. Figure 6.4 reveals that an unexpectedly high number of domestic/feral animals, almost exclusively cats, have been victims of carbofuran abuse (4).

6.5.3 Analytical methodology and recent developments

Analytical strategies at SASA have been adapted in accordance with technical developments in analytical instrumentation. In particular, the use of gas chromatography tandem mass spectrometry (GC/MS/MS), and, for compounds which are not amenable to GC/MS, liquid chromatography

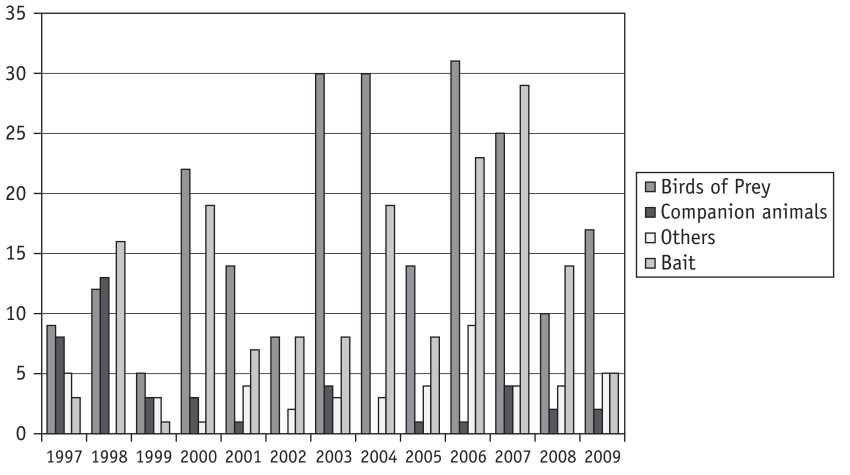

Figure 6.4 Type and number of specimens that tested positive for carbofuran between 1997 and 2009

tandem mass spectrometry (LC/MS/MS). Electron (EI) impact is the ionisation technique most commonly used for GC/MS and electrospray ionisation (ESI) is most commonly used for LC/MS. These techniques are employed exclusively by us for the determination of multiple-residues of a wide range of chemicals (including carbofuran and its metabolites) in a variety of matrices such as liver, kidney, bait, biological fluid, digestive tract material, and suspicious chemicals and substances.

The specific LC/MS/MS transitions: m/z 222 → m/z 165 and m/z 222 → m/z 123 are monitored throughout a designated time-scheduled data acquisition window, and used in conjunction with chromatographic retention time information to determine the presence of carbofuran in extracts from various samples associated with suspected poisoning incidents. The peak areas of the corresponding ion chromatograms are measured and quantified against a multi-point calibration curve generated following identical analysis of a set of calibration standards that cover an appropriate carbofuran concentration range (typically 0.01 mg/ml to 5 μg/ml).

Figure 6.5 shows the 'overlain' LC/MS/MS ion chromatogram (i.e., mouth content, stomach content and proximate 2 μg/ml calibration standard) relating to the positive determination of carbofuran in extracts from the mouth and stomach contents of a poisoned golden eagle (*Aquila chrysaetos* (inset in Figure 6.5)) found dead in Tayside, Scotland in June 2009. Golden eagles are afforded the highest protection status in the UK (3) and Scotland (4), and this particular incident received nationwide multi-media attention (5).

Following non-routine inspection of mass spectral data in a carbofuran positive sample, isofenphos was also found to be present. The data had been acquired using GC/MS in full-scan mode. Interrogation of the data revealed an unexpected background chromatographic peak, and subsequent spectral library searches indicated that the organophosphorus insecticide isofenphos was a 'top match'. This combination of carbofuran and isofenphos was significant, because the latter has never been approved for use in the UK. This suggests that the poison used in this case contained both compounds. When archived samples that had previously tested positive for carbofuran were re-analysed, some of these also tested positive for isofenphos.

Granular product formulations containing both substances, at 4.0% w/w (i.e., weight per weight) carbofuran and 2.0% w/w isofenphos, do exist. Such products, i.e., 'Yaltox-Combi' (refer back to

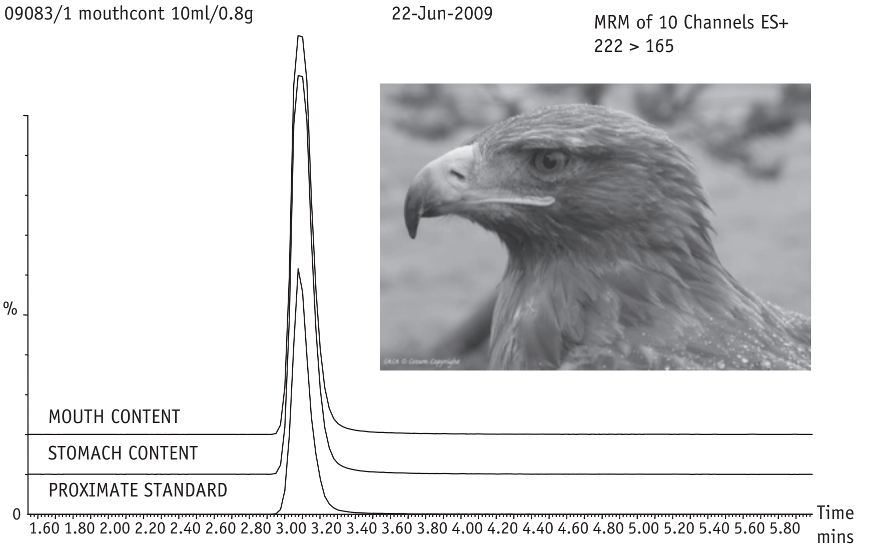

Figure 6.5 LC/MS/MS ion chromatograms (m/z 222 → m/z 165) associated with the confirmed poisoning of a golden eagle found dead in Strathclyde, Scotland (June 2009)

Table 6.2), although illegal in the UK, would seem to be accessible and are being used as poisons within Scotland. Hence, isofenphos is now routinely sought in all WIIS-Scotland analyses.

Recent analyses (made during 2010) have also highlighted that residues of carbofuran are detected whenever carbosulfan is detected, in or on a victim. Carbosulfan degrades to yield carbofuran (see Figure 1.10. in Chapter 1) and we have not yet found carbosulfan 'alone' in an animal, or at all in the liver of poisoned victims. This introduces uncertainty as to whether products containing carbofuran alone were used, or whether products containing carbosulfan in addition were involved. Carbosulfan is not approved for use in the UK and we are not aware of any formulations that contain both carbosulfan and carbofuran.

In recent years, the range and type of test specimens examined by SASA has been extended. Regular analysis of various poisoning paraphernalia (as shown in Figure 6.6) is also analysed, i.e., bags, clothing, implements/tools or particulate matter. These are usually collected from motor vehicles and from various containers recovered from the premises or in the possession of suspected offenders. In this respect, LC/MS/MS has been shown to have superior detection limits when compared to our existing GC/MS/MS methodology. The lowest calibration levels currently used for quantitative GC/MS/MS and LC/MS/MS are 0.2 mg/ml and 0.01 mg/ml, respectively. LC/MS also enables relatively straightforward sample preparation and screening for more polar, non-volatile or thermally labile metabolites of carbofuran (such as 3-hydroxycarbofuran or 7-phenolcarbofuran). Such compounds would not be detectable by GC/MS without additional and time-consuming derivatisation procedures.

6.5.4 Conclusion and discussion

Our analyses of data collected over the last 21 years indicates that carbofuran is gaining increasing popularity as a means to poison wildlife and other animals throughout Scotland. Despite the fact that

Figure 6.6 A typical poisoner's toolkit recovered during a field investigation (Grampian region of Scotland)

the chemical analyses carried out by SASA reveals the use of carbofuran to deliberately kill animals, successful prosecutions remain difficult to secure. For example:

1. It is rare for an offender to be ‘caught in the act’.
2. The victim(s) can often be discovered several kilometres away, and in any direction relative to the source of exposure to the poison.
3. The lethality of the chemicals involved may be disputed in court simply because they have not been clinically tested on the species in question.

Nevertheless, various Scottish Government departments, law enforcers/prosecutors and various stakeholders (e.g., landowners and managers, gamekeepers, non-government organisations such as the Royal Society for the Protection of Birds (RSPB-Scotland) and the Scottish Society for the Prevention of Cruelty to Animals (SSPCA)) are collectively committed to the detection, prosecution and ultimate eradication of all forms of crimes against wildlife. All associated activities are vigorously encouraged and supported by many Scottish Ministers. For example, in 2007, following a Parliamentary debate on wildlife crime, the Scottish Government announced ‘A Joint Thematic Inspection for the Arrangements in Scotland for Preventing, Investigating and Prosecuting Wildlife Crime’ (5). Scotland's Minister for the Environment also chairs meetings for the Partnership for Action Against Wildlife Crime in Scotland (PAWS) (6,7) and in 2010, Scottish Natural Heritage (SNH) was assigned by PAWS to administer ‘The PAW Fund for Fighting Wildlife Crime’ which awards grants for new and innovative projects tackling wildlife crime in Scotland (8).

For its part, SASA will continue to refine and develop analytical methodology, and exploit advanced technology and data manipulation software to ensure that the maximum amount of evidence is available for law enforcement. We have recently developed a new multi-pesticide residue LC/MS/MS screening process that includes carbofuran and its metabolites, and which complements our existing GC/MS/MS multi-residue method. This combination of analytical techniques significantly increases our capability to investigate accidental and/or deliberate poisoning (9). We would be happy to share the relevant protocols with readers of this book and any other interested parties.

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7 A Latin American perspective: the environmental impact of farming wheat and rice treated with carbofuran and Rhodamine B on Brazilian wild birds

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7.1 Introduction

Very few species of bird or mammal have ever caused multi-million dollar losses to the agricultural industry (Dolbeer 1999; Tobin 2002). However, to guarantee generous agricultural output, the large scale use of biocides has resulted in significant mortality among dozens of species of wildlife around agricultural sites (see Flickinger, King Stout et al. 1980; Eisler 1985; Cox 1991; Mineau 1993; Mineau, Fletcher, Glaser et al. 1999; McKay, Prosser, Hart et al. 1999; Vickery, Carter and Fuller 2002; Mineau 2005; Mineau, Downes, Kirk et al. 2005, American Bird Conservancy 2005). Many species found in agricultural areas do not pose a threat to crops, and one of the greatest challenges for pest and weed control technology lies in minimising adverse impacts to beneficial species, which can in turn help to regulate pest organisms in our farming areas and adjacent habitats.

Unfortunately, in Brazil (and in South America generally), very little scientific research has been carried out on the environmental impact caused by agrotoxins to wild fauna. The public is also poorly informed about this matter, probably because farmers and agrochemical companies are secretive about incidents and accidents. Government agencies responsible for wildlife conservation have also failed to invest sufficiently in vigilance and data collection, and do not disseminate the scarce

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information that is available. A scarcity of publications regarding this topic does not mean that there are low rates of mortality in birds poisoned by carbofuran in the agricultural fields of Latin America.

Animals that die (or are dying) from an agrotoxin poison often become the quarry of carnivorous mammals and birds of prey. Hence, whether through direct absorption, or secondary poisoning, the effect of the agrotoxin in the agricultural landscape can spread throughout the surrounding natural habitats. This effect is especially pronounced when populations are small and isolated (in forest patches, for example). Latin America continues to witness increasing forest fragmentation and this is the key driver behind the erosion of biological diversity within this part of the world (Harris 1984; Harris and Silva-Lopes 1992; Hagan, Haegen and Mckinley 1996; Colli, Accacio, Antonini et al. 2005; Prugh, Hodges, Sinclair et al. 2008). Incidents of secondary carbofuran poisoning are well documented in the United States and Canada, having caused substantial mortality in a diverse number of species (Eisler 1985; Mineau 1993; Mineau, Fletcher, Glaser et al. 1999, and see Chapter 8). In Brazil, however, there is a real shortage of data concerning poisoning for the vast majority of our fauna, regardless of the type of biocide used.

To conserve some of the natural pest control functions performed, farmers must find low-impact/sustainable methods of controlling pest biota. Otherwise, various trophic levels will suffer and this, in turn, will threaten the survival, adaptation and reproduction of numerous species such as birds of prey (e.g., Falconidae, Accipitridae, Strigidae, Tytonidae) and carnivorous mammals (e.g., Felidae, Canidae, Mustelidae, Procyonidae) both of which act to control so-called 'pest species' such as the eared-dove (*Zenaida auriculata*), the Picazuro pigeon (*Patagioenas picazuro*) and the Chopi-blackbird (*Gnorimopsar chopi*). Usually, predatory species move along/within the agricultural landscape matrix via the remaining uncultivated habitats. Such corridors provide a link between the remaining (albeit impoverished) populations.

Long-term consumption of prey poisoned/contaminated with carbofuran can cause chronic poisoning, which can negatively affect life expectancy, growth, physiology, behaviour and reproduction of a given species (Cox 1996). Short term, high level exposure to carbofuran will result in acute poisoning, causing the inhibition of the enzyme acetylcholinesterase (AChE), which generally leads to death through failure of the respiratory system (Baron 1991). The reader is referred to Chapter 2 for a detailed discussion of cholinesterase inhibition.

Carbamates tend to be extremely toxic and represent a group of insecticides commonly used in Brazil. Compounds such as carbaryl (Sevin), aldicarb (Temik), carbofuran (Furadan) and carbosulfan (Marshal) are widely used. Producers of grain such as wheat (*Triticum aestivum*), rice (*Oryza sativa*) and corn (*Zea mays*), use systemic insecticides such as carbofuran to guarantee the integrity of their harvests, since without pest control, their crops could be seriously compromised. The earliest applications of carbofuran in Brazil occurred in the late 1970s (Novaretti, Lordello, Nelli et al. 1980, Brancalion and Lordello 1981). Since the 1980s, carbofuran use has spread throughout Brazil and Latin America and it is applied to various crops, including bananas, tomatoes, corn (maize), soya, rice, wheat, sugarcane, cotton, peanuts, coffee and beans.

During seed treatment and post-planting treatment, liquid and granular formulations are used at various application rates (depending on the crop/pest target). Wheat and rice are often treated with carbofuran, carbosulfan and pyrethroids to tackle pests such as the lesser cornstalk borer (*Elasmopalpus lignosellus*), fall armyworm (*Spodoptera frugiperda*), dark sword-grass (*Agrotis ipsilon*), spittlebugs (*Deois flavopicta*, *Deois incompleta* and *Zulia entreriana*), white rice tip (*Aphelenchoides besseyi*) and various root-lesion nematodes of the genus *Pratylenchus*.

In accordance with a Brazilian Federal Decree (nº 4.074, January 2002), a systemic pesticide should be added to a seed mix in combination with a visible dye to reduce the risk of human ingestion. Hence, the toxic dye Rhodamine B, which has a reddish-purple colour, has been used for this purpose. Seeds then also become more apparent and attractive to granivorous wild birds such as *Columbidae* and *Icterinae*. Seeds treated with carbofuran and Rhodamine B, which are not

completely covered with soil during mechanical seeding, are eaten by granivorous birds foraging for food. This can then lead to direct mortality by deliberate ingestion or secondary poisoning, if predators ingest these poisoned birds. This problem is not confined to Brazil, but is also an issue in many countries where agrotoxin-laden seeds are used.

The majority of alternative methods used to mitigate bird mortality, due to poisoning from carbofuran and other pesticides and/or to avoid damages in several types of plantations, have involved scaring birds away from the area and preventing them from ingesting seeds with the use of acoustic, tactile, visual and/or gustative repellents. However, these measures, which add to the operational and financial burden of the agricultural operations, are not entirely satisfactory, and can themselves cause serious suffering to wild birds (Dolbeer, Ingram, Seubert et al. 1976; Avery, Humphrey, Primus et al. 1998).

Notwithstanding these findings and critical public opinion, studies have been developed to identify suitable chemical repellents and/or repelling colours (Tobin 2002; Hartley, Waas, O'Connor et al. 1999; Hartley, O'Connor, Waas et al. 2000) in an attempt to minimise the risk of poisoning wildlife with pesticides (Avery 2002). Preferences and aversions of animals for food are often related to the taste or appearance of the possible alimentary item (Zuberbuehler, Messikommer and Wenk 2002). Nevertheless, the fact that birds have a poorly-developed gustatory sense is a plausible reason for the limited results obtained by Avery, Humphrey, Primus et al. (1998) and Moran (2001), both of whom used chemical repellents in the absence of alternative food sources.

Birds tend to avoid primary repellents because they irritate their peripheral senses (i.e., taste, touch, smell, and hearing). Repellents that cause gastrointestinal injury are deemed secondary repellents. In this case, animals potentially learn to avoid such substances after an initial ingestion/exposure period. Secondary repellents are generally derived from agricultural pesticides, and are more effective. Primary repellents are commonly derived from natural products, and are promoted as causing less environmental impact, although they may also be less effective (Sayre and Clarck 2001).

Birds often use agricultural areas to feed on the abundant and accessible food resources available. If food is difficult to find, chew or digest, birds will spend more time and energy foraging. If birds are finding it difficult to maintain a positively-balanced ratio between energy spent over food gained (the theory of optimum foraging), they will search for new areas where food sources are more readily available (Avery 2002; Begon, Townsend and Harper 2006).

Camouflage is an evolutionary adaptation that can decrease an individual's chance of being detected within its environment (Zug, Vitt and Caldwell 2001; Frankel, Sousa, Cowan et al. 2004; Merilaita 2003). By using this principle a seed of wheat, corn or rice could first be treated with a systemic defence (e.g., a pesticide), then be treated with a dye to make it similar in colour and texture to the soil. This measure may ensure that any seed not fully buried by mechanical sowing, though technically exposed to a bird, is effectively camouflaged against the soil backdrop by other organic matter and surface irregularities. Thus, if effective, camouflaging could prevent the identification/detection of toxic seeds by birds in that area actively searching for them on the ground.

The camouflaged coated seed that we used in previous work had a surface that was dark brown, rugged and opaque. The use of this seed resulted in reduced consumption, and, consequently, reduced mortality of birds when compared with wheat and rice seed dyed with Rhodamine B (Almeida, Couto and Almeida 2010a). In addition, the camouflaged corn seeds were removed less frequently from the agricultural fields, in turn benefiting the farmer (Almeida, Couto and Almeida 2010b).

These findings can be explained because the brown seeds were probably absent or less obvious in the avian search image (Begon, Townsend and Harper 2006). Also, the seeds contrasted less against the soil background, hence their contours were less visually evident. The brown colour and the powder dye used, which is rich in iron oxide, decreases the spectral reflectance of the seed

(Hartley, O'Connor, Waas et al. 2000; Demattê, Epiphanio and Formaggio 2003; Almeida 2006) at the wavelengths visible to Passeriformes and Columbidae (Hart 2001). Thus, seeds blend into the soil. In addition, the camouflaged coating is opaque and less shiny when compared with seeds treated with Rhodamine B. This makes them less conspicuous (Schmidt, Scheiefer and Winkler 2004; Cuthill, Steves, Sheppard et al. 2005) and, in accordance with the optimal foraging theorem, greater energy would be required to consume and locate such seeds (Avery 2002).

In response to the number of incidents involving wild bird mortality caused by the ingestion of seeds treated with carbofuran in the Brazilian States of São Paulo, Goiás and Paraná, research in mitigation started in 1981 at the Department of Forestry Science, in the Superior School of Agriculture 'Luiz de Queiroz' at the University of São Paulo. Studies were conducted up until 1983, and aimed to protect wild birds on wheat plantations. However, the results of this work were never published, and wild bird mortality continued.

As time wore on and avian mortality persisted, assistance was sought in 2000 by a Brazilian agrochemical enterprise, and new research was undertaken between 2000 and 2002. In light of the new research findings, federal licences were granted by the Ministry of Health and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) in 2003. These licenses allowed the commercialisation of a camouflaged carbofuran-laced seed product which did not contain Rhodamine B. This formulation is still used in Brazil to mitigate the environmental impact of carbofuran on wild birds in rice and corn plantations.

The research conducted evaluated the avian mortality caused by conventional cultivation practices using seeds treated with carbofuran against that caused by alternate control methods. The work has been consolidated into a doctoral thesis (Almeida 2006), which is partially published (Almeida, Couto and Almeida 2010a; Almeida, Couto and Almeida 2010b). The work showed that seed camouflage can mitigate mortality and benefit avian species whilst controlling avian pests.

This chapter presents an evaluation of the environmental impact of conventional modes of wheat, corn and rice cultivation used today in Brazil, on dry and ploughed soil, with an emphasis on avian mortality caused by seeds treated with carbofuran and dyed using Rhodamine B. This chapter also compares the environmental impacts associated with the use of carbofuran, carbosulfan and methiocarb-treated seeds, with the latter two carbamate compounds being considered as alternatives to carbofuran, and all coloured with Rhodamine B.

Carbosulfan (Marshal) also has insecticidal and nematicidal properties, but it is considered to be around 20 times less toxic than carbuforan. As such, it could act as a viable chemical repellent if birds eating just one poisoned seed were able to associate the bad taste and the symptoms of toxicity before dying, and hence, halt further seed consumption. While carbosulfan is a less harmful agrotoxin than carbuforan and methiocarb (Mesurol) it is still an efficient carbamate insecticide. Although it causes vomiting and paralysis when ingested by birds, it has already been tested (to a point) as a secondary chemical repellent (Calvi, Grazio, Besser et al. 1976, Dolbeer, Avery and Tobin 1994), and the hope is that it will exert its repellent effect before causing mortality. A discussion regarding the chemical properties of carbosulfan and its efficacy as an insecticide relative to carbofuran can be found in Chapter 1. Methiocarb is also a carbamate insecticide, and can be viewed as a secondary chemical repellent since it causes vomiting and paralysis when ingested by birds (Calvi, Grazio, Besser et al. 1976, Dolbeer, Avery and Tobin 1994).

7.2 Materials and methods

Experiments at rice and wheat plantations were performed in the southeast of Brazil in the municipality of Assis (State of São Paulo), in Cambará and Floraí (State of Paraná), and in central Brazil, in Palmeiras de Goiás (see Figure 7.1). These are all regions where farmers have reported avian mortality due to the ingestion of seeds treated with pesticides.

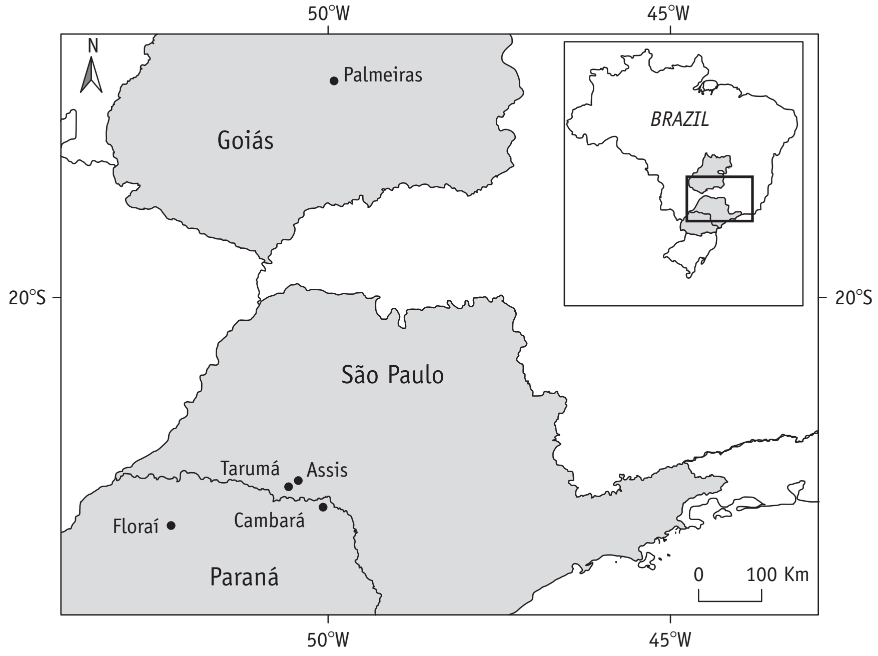

Figure 7.1 Experiments on rice and wheat plantations were performed in the municipalities of Assis, Cambará, Floraí and Palmeiras de Goiás. There were large eared-dove (*Zenaida auriculata*) colonial breeding in sugarcane plantations of the Tarumã and Cambará municipalities

Experiments were performed during the planting season, in September 1981, April 1982, and January, February and October 1983, when numerous bird flocks were present. Seven conventional sowings of wheat or rice seeds treated with carbamates and dyed with Rhodamine B were conducted in the dry soil plots. The ploughed soil plots were sown once using a tractor-mounted gravity seed drill in the traditional planting manner (see Figures 7.2a and 7.2b).

Table 7.1 shows the treatments used in experiments 1 to 7, giving the concentration, dosage and toxicity of the three carbamate compounds applied. Table 7.2 also gives the conditions used in these experiments, i.e., location, type and quantity of seed used, total area of plot, days of research, and number and size of individual plots. Figure 7.3 shows the shape and distribution of plots.

Each plot was searched twice a day for dead birds. The search parties were composed of two, three or sometimes four people, walking slowly (~3 km/h) or driving in a pick-up truck (~5 km/h). Searches were undertaken within and around the plots. Bird carcasses were collected and the species identified. Food present in the digestive tract of each bird carcass was collected from: i) the crop and oesophagus; ii) the proventriculus; and iii) the gizzard. Any seeds recovered were counted.

In experiments 1 to 7, small (~40 g) and medium-sized birds (~120 g) ingesting seeds often died within the treated plot. An evaluation of the effect of carbofuran on wild birds was undertaken in these experiments. The mean, standard deviation and confidence interval ($\alpha = 0.05\%$) of mortality was calculated, and the confidence intervals were computed using the student's t distribution.

(a)

(b)

Figures 7.2a and 7.2b A tractor-mounted gravity seed drill, used in the traditional planting manner. Figure 2a shows the rice experiment in Palmeiras de Goiás, beside a cerrado forest fragment; 2b shows a wheat experiment in Assis, São Paolo
Photos taken by Álvaro Fernando de Almeida

A comparison between the number of deaths consistent with ingesting seeds treated with carbofuran, carbosulfan and methiocarb was made for experiments 4 and 6. In the fourth experiment, treatments applied to the rice seeds were: i) carbofuran and Rhodamine B; ii) carbosulfan and Rhodamine B. In the sixth experiment, treatments applied to the wheat seeds were: i) carbofuran and Rhodamine B; ii) carbosulfan and Rhodamine B; iii) carbofuran and Rhodamine B plus methiocarb (methiocarb was added to the seeds after they received treatment with carbofuran and Rhodamine B). In experiments 4 and 6, the amount of seed in plots and among treatments was balanced. All seed was treated in specific machines designed for commercial-scale planting.

The variation in the number of birds that died between treatments in experiment 4 (testing carbofuran *versus* carbosulfan) and in experiment 6 (testing carbofuran, carbosulfan and methiocarb) was analysed using Kruskal-Wallis analysis of variance. This statistical procedure was performed

Table 7.1 Treatments to evaluate the impact of seeds treated with carbofuran consumption on wild birds in the experiments 1 to 7, as well as possible mitigating mortality treatments in the experiment 4 (carbosulfan compared to carbofuran) and experiment 6 (comparing methiocarb, carbosulfan and carbofuran)

Experiment(s)	Treatments	Concentration	Dosage	LD_{50}*
1 to 7	carbofuran	350 g/L	2 L/100 kg seeds	8–12 mg/kg
4	carbosulfan	350 g/kg	3 kg/100 kg seeds	250 mg/kg
4	carbofuran	------------ Idem experiments 1 to 7 ------------		
6	methiocarb	750 g/kg	1kg/100 kg seeds	20 mg/kg
6	carbofuran	------------ Idem experiments 1 to 7 ------------		
6	carbosulfan	---------------- Idem experiment 4 ---------------		

Wheat and rice seeds in all treatments were dyed with Rhodamine B, see also Table 7.2
*Median Lethal Dose, according to World Health Organization (2009)

Table 7.2 Experiments (Exp.) to evaluate the impact of consumption of seeds treated with carbofuran and dyed with Rhodamine B on wild birds (Exp. 1 to 7) and possible mitigating mortality treatments: (Exp. 4, 6) carbosulfan plus Rhodamine B; (Exp. 6) methiocarb plus Rhodamine B (see Table 7.1)

Exp.	City	Seed Species	Seed (kg)	Area (ha)	Days of search	Number of plots	Size of plots (ha)
1	Assis, Cambará	wheat	675	5	8	5	1
2	Assis	wheat	1750	8.5	4	1	8.5
3	Palmeiras de Goiás	rice	150	6	3	2	3
4	Assis	rice	364	3.64	8	14	0.26
5	Assis	rice	800	8	4	30	0.25
6	Assis	wheat	300	2.1	3	3	0.7
7	Floraí	wheat	3500	24	4	1	24

considering eight and three days of experimental exposure, respectively, in experiments 4 and 6. Feathers spots (i.e., piles of feathers) where birds had been predated, and birds which were found to have ingested seeds from more than one treatment, were excluded from the analysis of variance.

7.3 Results and discussion: biological aspects of the environmental impact caused by carbofuran and Rhodamine B in Brazilian wild birds

The predominant species poisoned by seeds treated with carbofuran and Rhodamine B were birds that fed on grain and sometimes small arthropods. These were medium-sized species such as the Picazuro pigeon and small species such as the eared dove, ruddy ground dove (*Columbina talpacoti*) and Chopi

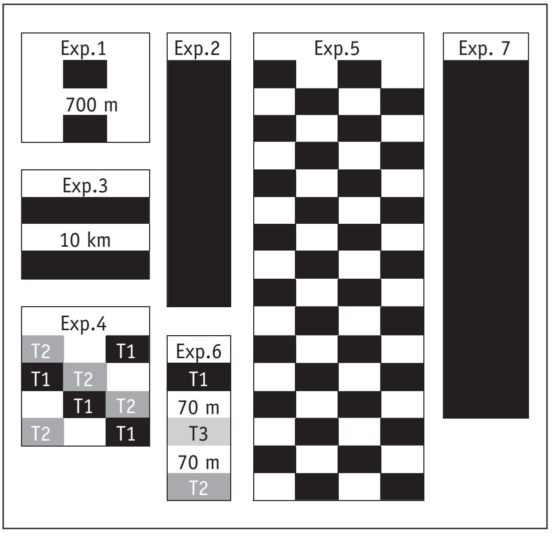

Figure 7.3 Field design of plots in all seven experiments (Exp.) for evaluating the impact of seeds treated with carbofuran and Rhodamine B consumption on wild birds, where: T1 – red seeds treated with carbofuran and Rhodamine B; T2 – red seeds treated with carbosulfan and Rhodamine B; T3 – red seeds treated with carbofuran and methiocarb. Distances between plots of the same experiments were 70 m, 700 m and 10 km

blackbird. All these species are common in rural areas, and sometimes cause damage to corn, wheat, rice and soya crops in the Brazilian States of São Paulo, Paraná and Mato Grosso do Sul.

Details regarding the 13 species and 465 birds found dead in the experiment are given in Table 7.3. Data includes partial carcasses and feather spot data, which represents birds that were partially consumed or totally removed by predators. Granivorous birds represented 97% of the species poisoned. The eared dove was most common, which accounted for as much as 89% of the total number of individuals found dead (see Figure 7.4). This species increased in numbers dramatically in the 1980s, especially in the State of São Paulo. As a result, large productive colonies supply nutritional support for a range of predatory species, such as the southern crested caracara (*Caracara plancus*) and the roadside hawk (*Rupornis magnirostris*). Such predators regulate these agricultural pests, and can be very abundant as observed, for example, in large groups of crested caracaras.

Although only two roadside hawks were found dead (refer to Table 7.3), the behaviour of this species and that of the southern crested caracara (seen attacking, removing and carrying poisoned birds in flight, probably to their chicks), was documented in four experiments.

Numerous attacks by predators were also detected from the piles of feathers found (i.e., feather spots), and it was possible to distinguish the actions of predatory mammals of the carnivorous order, by identifying dental cuts on feather spines (the calamus). By dissecting the digestive system of one of the roadside hawks, we revealed that it had eaten an eared dove. Parts of the dove were found in the hawk's throat, its gizzard and its proventriculus. Feathers, various parts of the bird's digestive system, and five wheat seeds treated with carbofuran and Rhodamine B were also found. These observations confirmed that predators are victims of secondary poisoning, and indicated that birds and mammals which attack dead or dying granivorous birds can be poisoned.

Predator poisoning can cause wide ranging environmental impacts and may harm the potential for survival of various already fragmented populations. Likewise, the biological stability between

Table 7.3 Quantitative list of 13 species of pesticide-intoxicated birds observed in wheat and rice planting experiments

Bird species	Number of victims per experiments						
	Exp.1	Exp.2	Exp.4	Exp.5	Exp.6	Exp.7	Ind.
Zenaida auriculata Eared Dove	4	19	146	5	162	29	365
Columbina talpacoti Ruddy ground dove	11	.	.	1	3	.	15
Gnorimopsar chopi Chopi blackbird	.	5	3	.	.	.	8
Athene cunicularia Burrowing owl*	3	.	.	.	.	4	7
Patagioenas sp Pigeon	.	.	.	2	.	2	4
Rupornis magnirostris Roadside hawk*	2	.	.	.	.	.	2
Patagioenas picazuro Picazuro pigeon	.	.	.	.	.	1	1
Falco sparverius American kestrel*	.	.	.	.	.	1	1
Leptotila rufaxilla White-tipped dove	1	.	.	.	.	.	1
Nothura maculosa Spotted nothura	.	.	.	.	.	1	1
Nystalus chacuru White-eared puffbird*	.	.	.	.	.	1	1
Passer domesticus House sparrow	.	1	.	.	.	.	1
Pitangus sulphuratus Great kiskadee*	.	1	.	.	.	.	1
Zonotrichia capensis Rufous-collared sparrow	1	.	.	.	.	.	1
Bird carcasses dissected	22	26	149	8	165	39	409
Total of intoxicated victims	25	38	149	30	183	40	465

Legend: Exp. – experiment; Ind. – the total number of individuals intoxicated for each bird species; asterisk (*) indicates carnivorous birds; absence of asterisk indicates granivorous-insectivorous species. Total of intoxicated victims include dissected carcasses and feather spots of victims attacked by predators.

predator and prey may be undermined, which can then have repercussions for farmers. Since predators often have a large body mass (and poison ingestion rates may be smaller), it can take longer for secondary poisoning to take effect, and animals may well shift or seek refuge in adjacent forests. Such birds would not be detected in our mortality counts, hence our evaluation regarding the effect of carbofuran (at higher trophic levels) represents an underestimation. We strongly recommend that studies regarding impacts on predatory birds and mammals, which carry carbofuran in their body tissue, or in poisoned prey to the forests, be conducted.

Figure 7.4 Eared dove (*Zenaida auriculata*) was the species of bird that incurred the most deaths. This photo shows one of the 365 eared doves that died after consuming wheat seeds treated with carbofuran and Rhodamine B. Beside it (highlighted by the arrow) is one of the seeds that had not been buried during the seeding process, remaining dangerously exposed to other granivorous birds. *Photo taken by Álvaro Fernando de Almeida*

Eleven insectivorous birds (refer to Table 7.3) that died with symptoms of carbofuran poisoning were unexpected victims, since no treated seed was found in their digestive tract. The possible mode of poisoning in this case is not clear, but such data indicates a potential danger may exist to these species.

We also found several burrowing owls (*Athene cunicularia*) and a roadside hawk (see Figure 7.5) dying with contracted pupils and compromised motor coordination. The roadside hawk was found beside its regurgitated food, in which only arthropod remains were noted. The digestive systems of the burrowing owls, American kestrel (*Falco sparverius*), great kiskadee (*Pitangus sulphuratus*), white-eared puffbird (*Nystalus chacuru*) and the other insectivores were also empty. This may suggest that these species regurgitated any food carrying the poison. Vomiting is in itself a sign of carbofuran poisoning (see Chapter 2). It is possible that the powdered dye used to camouflage seed poisoned arthropods which were then consumed by insectivorous birds. During sowing with camouflaged seed, clouds of dust were often kicked up by the sowing machines (Almeida, Couto and Almeida 2010a).

The capacity of certain birds to regurgitate poisoned seed may also contribute to a decrease in their mortality (Pascual, Hart and Fryday 1999). The digestive systems of several other dead granivorous birds (four individual Chopi blackbirds, house sparrow (*Passer domesticus*) and spotted nothura (*Nothura maculosa*)) were also found to be empty.

Some birds were found poisoned with a few carbofuran-treated seeds still in their crops, which is used as a temporary pre-digestive food store and not for nutrient absorption. Seven dead ruddy ground doves were found with one or two seeds, and 25 eared doves died with only one seed in their crop (see Figures 7.4, 7.6 and 7.7). These observations indicate that carbofuran, even in extremely small amounts, can be absorbed via the avian crop, perhaps through

Figure 7.5 At a farm planted with carbofuran-treated wheat, this young roadside hawk (*Rupornis magnirostris*) was unable to fly and escape, exhibiting erratic movements and vomiting, symptoms of poisoning by carbofuran. This predator probably became poisoned after eating birds or insects already affected by the pesticide.
Photo taken by Álvaro Fernando de Almeida

Figure 7.6 A pair of ruddy ground doves (*Columbina talpacoti*), (male on the right) next to various wheat seeds treated with carbofuran and Rhodamine B of the type that killed these birds.
Photo taken by Álvaro Fernando de Almeida

Figure 7.7 Throat dissection of a ruddy ground dove (*Columbina talpacoti*) showing the consumption of treated wheat seeds that led to the bird's death. Note the presence of wheat seeds treated with carbofuran and Rhodamine B (I), as well as seeds treated with carbofuran camouflaged with brown dye (II). Birds that had ingested seeds from more than one of the treatments were excluded from the analysis.
Photo taken by Álvaro Fernando de Almeida

mucus membranes. Such exposure is fatally toxic to eared dove (~120 g) and ruddy ground dove (~40 g). This is similar to a finding made by M. Odino in Kenyan rice fields, as detailed in Chapter 3.

The evident ingestion of red seeds (from the Rhodamine B coating) suggests that this colour is not aversive to birds, which is in contradiction to the findings of Avery and Mason (1997) and Nelms and Avery (1997). The colour instead seems to attract at least certain species (Schmidt, Scheiefer and Winkler 2004; Cuthill, Steves, Sheppard et al. 2005). The spectral quality of this colour is contrasting and conspicuous to birds. This may explain why higher seed consumption occurred when seeds were treated with carbofuran and Rhodamine B.

7.3.1 Alternatives and mitigation

During the eight days spent on experiment 4, comparisons were made between the effects of carbofuran and carbosulfan, using rice seeds dyed with Rhodamine B. In plots where seeds treated with carbofuran were sown, 109 birds were found dead, and in those treated with carbosulfan, 40 were recovered. These results differed significantly ($H = 63.01$; $p = 0.012$; $df = 1$; $n = 8$). Greater mortality was caused by carbofuran, suggesting that the use of carbosulfan may lessen the impact of grain farming on wild birds. In turn, data clearly showed that carbosulfan use will still result in notable mortality. Further, some birds were noted as having been visibly poisoned by carbosulfan, yet managed to leave the test plot and (though disorientated) reach refuge outside the test area (ca 550 metres away). We do not know if these poisoned birds recovered or died after escaping the experimental plot.

Table 7.4 Rate of dead birds recovered per day during the experiments with carbofuran, carbosulfan and methiocarb

Number of the Experiment	Seed Treatment	Number of Dead Birds	Mean and StDev
4	Carbofuran	109	13.6 ± 7
4	Carbosulfan	40	5 ± 5.5
6	Carbofuran	82	32 ± 19.42
6	Carbosulfan	21	6 ± 5.7
6	Methiocarb	62	20 ± 13.01

Given these points, we must consider that: i) poisoned birds may leave the test plot); ii) carbosulfan does not act as a secondary repellent which interrupts consumption; iii) birds poisoned with carbosulfan may have a greater tendency to reach the adjacent forest, where they may be preyed upon by forest species, some of whom have a higher 'conservation value'; iv) birds affected by carbosulfan may seek refuge in denser vegetation, and may therefore be hidden from farmers, researchers and hence, public opinion.

These points raise questions regarding the principle that carbosulfan (which is 20 times less potent) could be used as a substitute for carbofuran. The findings reported here suggest that carbosulfan is probably not an effective alternative to carbofuran. Although carbosulfan is (on paper, for a limited number of species tested) less toxic, birds that ingest only a few seeds treated with carbosulfan may still not survive. For example, only six or seven rice seeds were enough to kill several eared doves (n = 4). The capacity for a bird to recover from nominal ingestion of a few carbosulfan-treated seeds is also unknown.

The possible repellent effects of methiocarb and carbosulfan, as tested in experiment 6, were not statistically proven (Table 7.4). In the treatment with methiocarb, 62 birds died (and an average of 20 individuals died per day); while similar results were obtained using carbofuran, where 82 birds died at a rate averaging 32 per day. Although fewer birds died when carbosulfan was used (21 individuals at 6 deaths per day), as in the previous experiment, many birds visibly affected by carbosulfan escaped the test plot, making an accurate estimation of mortality difficult.

Although certain authors have indicated that methiocarb may act as a secondary repellent in birds (Nelms and Avery 1997; Avery, Tillman and Laukert 2001; Avery 2002), its use in association with carbofuran was limited. Carbofuran is an extremely toxic pesticide, and only one treated seed is needed to kill a small or medium sized bird. Thus, the toxicity of carbofuran simply over-rides any potential benefits that could be gained from adding methiocarb. Moreover, no warning communication between birds was observed, nor any signs of aversion due to the ingestion of carbosulfan or methiocarb, which would have reduced seed consumption.

7.3.2 Avian mortality and some aspects that influence this estimate

The following farming practices and factors may influence the accurate estimation of mortality rate, and must be taken into consideration when determining how to mitigate mortality:

i) movements of machinery and other farming activities

ii) regulation of sowing machinery

iii) presence of roots, plant debris (litter), and surface depressions of the soil which impede the burial of seeds

iv) falling of seeds on compacted ground or on surfaces with no organic matter

v) large concentrations of birds in the immediate area

For example, during experiment 6, birds often concentrated within the treatment plot in areas some distance from where tractors were actually operating. It is important that, while there is sown seed on the soil surface, farm machinery must be used in a way that does not scatter (or scare) birds into areas where carbofuran treated seed is exposed and readily available.

In addition, in areas of forest that have recently been cleared (as was the case in experiment 3), or, when no tillage is used, waste vegetation, roots, thickets, branches and logs may all hinder seed burial, again increasing the risk that birds will be exposed. Zero tillage has been used widely in Brazil, where seed is sown onto un-ploughed land (which maintains remnants of the previous crop). Also, in order to attain better germination, farmers may adjust their sowing machines so that seeds are buried only a few centimetres (~5 cm) below the surface.

Sowing machine operators will also often manoeuvre machines whilst still spreading seed. This means that seed volume per unit area can be excessive, or seeds are spread outside the planting area, i.e., onto compacted dirt roads lacking organic matter. Seeds are then far more visible to birds, and stand out. This increased conspicuousness results in high mortality, which is often recorded near the roadside.

In experiment 2, adjacent to the experimental plot, was a recently harvested rice crop. This area offered abundant food, attracted a large number of birds, and hence mortality in our experimental plot was not mitigated (to an acceptable level) by camouflaging the seeds (Almeida 2006). Depending on the site and time of year, very high numbers of birds can be attracted to rice, wheat and sugarcane plantations. The latter can be especially attractive to eared doves which flock there in search of overnight refuge, and a place to nest. Thus, when there are known to be high numbers of birds in an area immediately surrounding a proposed planting site, farmers should ideally delay seeding, or harvest the crop which is attracting the birds (Hawthorne 1987).

Where eared dove flocks were present, the minimum number of birds poisoned was between 25 and 183 (excluding experiment 3, where no dead birds were found, which we view as atypical; see Table 7.3). Thus, in plots where there was mortality, the average plot size was 8.54 hectares ($n = 6$; standard deviation $= 7.8$). The estimated number of birds expected to be poisoned was therefore 77.5 ± 55.7 ($n = 6$; standard deviation $= 69.6$, $\alpha = 0.05$). Therefore, we would expect an average of approximately nine deaths per hectare, at a minimum rate of 2.5, and a maximum rate of 15.6 birds per hectare.

Such estimates need to consider that the mortality caused by carbosulfan was probably not accurate because birds escaped into the surrounding habitat before dying. Moreover, counts did not provide a full tally of secondary poisoning mortality rates of predators who left the area or those carcasses removed by scavengers before being counted (as described by Mineau 2005). The above estimates are therefore conservative. They are, however, similar to those made for North America in corn crops, where carbofuran was used in granular form. Here, in Iowa and Illinois, between three and 16 dead birds were estimated to die per hectare (Mineau 2005). Such a comparison is valid, since similar methods were used when searching for dead birds. Also, consumption rates for rice, wheat and corn seed by birds on such farms is often similar (Almeida, Couto and Almeida 2010b).

These estimates regarding the number of birds potentially poisoned on Brazilian farms are very worrying. Agrotoxins like carbofuran are used on a very large scale in Brazil, and improper use occurs throughout the agricultural landscape. Governmental control is severely lacking and millions of hectares are devoted to rice, wheat, and corn production. Species such as the eared dove are abundant in some regions, and they may be both victims and vectors, effectively passing the agrotoxin legacy up the food chain to predators (some of whom may be rare) as the poisoned doves are predated or scavenged.

Outbreaks of eared doves in South America have occurred where two common/anthropogenic factors meet. Firstly, waste from mechanical harvesting provides abundant grain based food throughout the year, and secondly, the mosaic landscape with large homogeneous patches of dense vegetation is highly suitable for colonial breeding. This commonly occurs close to cropped fields, for example in sugarcane plantations in the southeast of Brazil (Bucher and Ranvaud 2006). In addition, large-scale deforestation in southeast Brazil has swept away 92 to 97% of the native vegetation (Ranvaud, Freitas, Bucher et al. 2001). Such factors can favour vast breeding colonies, some covering 40 to 1 000 hectares, and five and ten million breeding birds may be located in such sugarcane fields (Ranvaud and Bucher 2006).

Over the past 30 years, eared dove numbers have risen dramatically throughout such regions. Farmers in the 1980s reported widespread damage to crops, as birds fed on emerging soybean seedlings and enormous flocks landed in rice and wheat plantations (Ranvaud, Freitas, Bucher et al. 2001). Control measures were initiated which included the intensive destruction of nests. Eggs and chicks were collected during the day, and adults were caught at night, with the help of torches. Chicks and eggs were buried alive and adults were collected and consumed by farm workers. Although Brazilian wildlife protection laws do not allow hunting (Federal Law 5197 of 1967), expeditions to gather doves were organised by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). The IBAMA authorised the gathering and consumption of the doves, but not the sale or direct poisoning of them (Ranvaud, Freitas, Bucher et al. 2001, and authors' personal observation).

However, during the 1990s, many farmers did deliberately poison the eared doves, offering them carbofuran plus Rhodamine B treated wheat grain along the soybean plantation lines. This caused the deaths of thousands of eared doves and of many other granivorous birds (*Columbidae*, *Emberezidae*, *Icteridae*) and predators (through secondary poisoning), mainly owls (*Strigidae* and *Falconiformes*). Such intentional poisoning continued for circa ten years (personal observation). Besides disrupting the ecological balance within affected regions, human and animal consumption of eared doves that were deliberately poisoned or exposed to dangerous pesticides (like carbofuran and others in agricultural fields) represented a real risk of intoxication via secondary poisoning for rural workers and predatory/scavenging fauna. These practices have been undertaken for circa 20 years (until recently), yet efforts to eliminate the eared dove have proven inefficient. Their population density remains high in certain regions, and they continue to seriously damage crops (Ranvaud, Freitas, Bucher et al. 2001; Bucher and Ranvaud 2006; Ranvaud and Bucher 2006).

Evidence from other locations (Bucher and Ranvaud 2006) suggests that a lower food supply maintains smaller populations of eared doves with no damages to the agriculture, but, for this, it is necessary to keep the agricultural landscape under less intensive uses, with a lower proportion of areas producing grains throughout the year.

In States such as São Paulo, Paraná, and Goiás, the conservation of biodiversity (just like the ecological balance in agriculture) greatly depends on the permeability of the landscape to native species in the private properties, because areas of semi-deciduous Atlantic Forests and Cerrado (a savannah-like biome) are now extremely diminished, fragmented and selectively harvested (Alho and Martins 1995; Durigan, De Siqueira and Franco 2007; Diniz-Filho, Oliveira, Lobo et al. 2009; Ribeiro, Freitas, Bucher et al. 2009). Likewise, the Federal and State protected areas are few, small, badly-distributed, and managed with rather poor resources (Almeida and Almeida 2003; Lairana 2005; Olmos 2005; Fonseca, Lamas and Kasecker 2010; Melo, Pinto and Tabarelli 2010). Even in some large and well-managed North American parks, species fragmentation and isolation, driven by an increasingly anthropogenic landscape, which is scarcely permeable to wildlife, may cause local extinction, as is the case for 14 mammal species (Newmark 1987).

Thus, in order to avoid exceeding pest outbreak thresholds (Bucher and Ranvaud 2006) and biodiversity extinction thresholds (Andrén 1994; Fahrig 2002; Fahrig 2003; Radford, Bennett and

Cheers 2005) a minimum amount of original (i.e., pristine) habitat needs to be maintained within any landscape. However, for many years, agribusiness groups in Brazil have vigorously attempted to alter the Brazilian Forest Act (Federal Law 4771/1995)*, in an effort to essentially minimise the requirement for conservation areas within private property (Almeida and Almeida 2003). If such efforts were approved by the Brazilian Congress, rules will then benefit the clear-cutting of forests and savannahs, and reduce the need to restore illegally-cleared native vegetation. Species-area relationship analysis has projected the extinction of more than 100 000 species if this type of plan went ahead, a massive loss which will invalidate any previous commitment made to biodiversity conservation (Metzer, Lewinsohn, Joly et al. 2010). Any increase in the proportion of productive agriculture may also result in a rise in certain agricultural pests, and thus a higher dependence on pesticides, as has happened in southeast Brazil.

Population declines noted for several bird species in agricultural areas in Europe and Canada (Mineau, Downes, Kirk et al. 2005) are suspected to have been caused, at least in part, by the use of pesticides (McKay, Prosser, Hart et al. 1999; Vickery, Carter and Fuller 2002). The high mortality rates we note here for Brazil are consistent with existing findings (Eisler 1985; Agriculture Canada 1993; Mineau, Fletcher, Glaser et al. 1999; Mineau 2005) regarding the potential impact that carbofuran exposure can have on wild birds.

Given these findings, research must be intensified to evaluate the magnitude of the impact that pesticides are having on Brazilian fauna and on the modes of application and formulations that have been banned in developed countries, but that are still in use in Brazil and probably in many other parts of Latin America, on large commercial scales, with government permissions. Pressure should be placed on the Brazilian Federal Government, since the continued use of carbofuran and Rhodamine B is in conflict with Brazilian Law (Number 7802, July 11, 1989), which specifically prohibits the registration of pesticides (and components) that may cause damage to the environment.

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Note

*The new Brazilian Forest Act received an enthusiastic preliminary approbation on 24 May 2011. A vote will be held in the National Senado (Senate), likely in September of 2011, and the final phase will be for the Act to be passed by the Senado and then the President.

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8 Impacts of carbofuran on birds in Canada and the United States

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8.1 Introduction and short registration history of carbofuran in North America

The only manufacturer of carbofuran in the United States and Canada is the FMC Corporation although, in Canada, carbofuran was sold and distributed by the Bayer Corporation. (The first Canadian labels, in 1970, were in the name of Niagara Chemicals, a division of FMC Corporation). The only spray formulation of carbofuran marketed in North America is a 'flowable' formulation, which is a finely milled paste in a thick suspension. This formulation is known as Furadan 4.8 F, 480F or Furadan 4F though these products are identical. The applicator must mix the flowable formulation with water and agitate thoroughly to mix; otherwise, there is a high risk that the application rate and ensuing residues will vary widely between different parts of the treatment area. Registration authorities in Canada also reviewed a wettable powder formulation (75 WP) but, apparently the latter was not registered – or if so not for very long.

Several granular formulations are registered for use in North America. The principal type contains a sand core (silica) and is marketed as 3G, 5G, 10G, or 15G formulations which comprise 3, 5, 10 or 15% active ingredient (% ai) by weight respectively. The FMC also experimented with a 2G formulation in rice (Flickinger, King, Stout et al. 1980). The 10G granule was the most commonly used on row crops; the 3 and 5G products were used primarily in rice. This material has the appearance of small round beads, about the size of beach sand, typically dyed pink, purple or

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blue. This material is deposited directly into the seed furrow (in-furrow) or applied as a wide strip (banded) over the seed furrow but extending approximately 10 cm on either side. This wider band is designed to provide protection to the developing tap roots of the maize as the insecticide, dissolved in rain water, percolates into the soil.

In Canada, through a commercial arrangement with FMC, the Bayer Corporation also sold 5 and 10% granules on a corncob base (granulated dried maize cob) for use in oilseeds (canola or oilseed rape and mustard) at seeding. Bayer marketed the 10% granule as Furadan CR-10. These granules are slightly larger and more angular in shape – more like fine gravel; therefore they do not 'flow' as well as the silica granules. They are mixed with and planted directly with the seed, typically canola (oilseed rape).

In the United States, the Environmental Protection Agency (US EPA) began its re-evaluation of granular formulations of carbofuran in 1985, after FMC conducted a field study in Utah (described later in 8.2.1.2). This study showed substantial mortality, in line with the predicted risk from the original assessment. The US EPA and the manufacturer (FMC) reached a negotiated settlement in 1991, leading to the gradual phaseout of the main use patterns. However, as recently as 2002, the agency proposed relaxing restrictions for emergency use in rice (where a State requests a supplementary registration on the basis of a perceived agronomic necessity), which some environmental groups contested. These emergency uses were eventually denied. The use of Furadan 4F continued until 2009, despite ample evidence from industry field studies mandated by the agency and submitted in 1989 that the product caused regular and predictable avian mortality. Effective from December 2009, the US EPA revoked all tolerances for carbofuran, effectively prohibiting all uses on food crops. The EPA also issued an 'Intent to Cancel' notice for carbofuran, and has now cancelled all uses. Evidence of ecological effects, including wildlife kills, was considered in this decision as well as risks to human health.

Soon after farmers began using carbofuran in Canada in 1973, reports of bird kills started coming in. Field investigators documented at least four different incidents in British Columbia (BC) between 1973 and 1975 that involved a total of more than 1 300 bird deaths. There was substantial unfavourable publicity associated with these bird kills, and, in 1976, FMC withdrew the 10G formulation from BC. Flooded fields, slow breakdown of granules in acidic soils, and extensive use of agricultural fields by waterfowl exacerbated the risk to bald eagles (*Haliaeetus leucocephalus*) and other birds of prey (see Section 8.5, further on). Notwithstanding the history of bird die-offs, agricultural authorities encouraged FMC to reintroduce the product in 1986 (P.W. McMullen, Chemagro Ltd., personal communication). A kill of 500 to 1 200 songbirds occurred that same year in a turnip (rutabaga) field, and it is likely that more waterfowl and scavengers died.

In response to continuing pressure from the Canadian Wildlife Service (CWS) of Environment Canada, Canadian regulatory authorities announced a special review of both granular and liquid formulations in June 1990 (Agriculture Canada 1990). The present chapter takes its root in an unpublished report (Mineau 1993) that reviewed the demonstrated impacts on birds of both the granular and liquid formulations of carbofuran in Canada and the US. That report formed the basis of the Canadian case for regulatory review of the product by the Canadian Department of Agriculture (the regulatory authority at the time). For that review, Mineau (op. cit.) examined all original investigation and incident reports so as to provide as much detail as possible to the regulators. For incidents documented after that date with the flowable formulation, we relied largely on a compilation by the US EPA (Fite, Randall, Young et al. 2006); therefore, these accounts are less complete. In the present chapter, we only review field studies and incidents. A few small pen (i.e., simulated field) tests have also been performed with this insecticide (e.g., Martin, Solomon, Forsyth et al. 1991; Somers, Kumar, Khan et al. 1991; Martin and Forsyth 1993; Martin, Johnson and Forsyth 1996) but their inclusion would require a more in-depth review of simulated field tests and whether they accurately portray actual exposure. We have therefore chosen to omit them. Other reviews of the impacts of

carbofuran in North America have been written (e.g., National Research Council of Canada (NRCC) 1979; Eisler 1985) but without the level of detail provided here on the bird impacts.

In December 1995, the Canadian regulatory authorities cancelled all silica-based granular formulations and ordered the manufacturer to conduct field trials on the corncob formulations. FMC Corporation, in concert with the Bayer Corporation, carried out these trials in early 1997 and submitted the results in the autumn of 1997 to government regulators. In December 1998, the Pest Management Regulatory Agency (the new regulatory authority following a 1996 reorganisation of the pesticide registration system in Canada) announced a full cancellation of all granular registrations because of unacceptable risks to birds.

In December 1995, the regulatory authorities also cancelled some uses of the flowable carbofuran after results of a study showed that the product was adversely affecting the endangered burrowing owl (*Athene cunicularia*). This effect occurred despite the very low application rate of 132 grams of active ingredient per hectare (denoted as g ai/ha). This is revisited later in Section 8.4.2.3. However, the regulators allowed continued use for corn and potatoes, notwithstanding the higher application rates on these crops and the fact that carbofuran use had caused avian mortality at these rates and on similar sites. The Pest Management Regulatory Agency (PMRA), Canada's regulatory authority, re-opened its review of the remaining uses of carbofuran along with several other carbamate pesticides in 2002. In July 2009, in step with US EPA proceedings, the PMRA proposed the cancellation of all remaining uses of carbofuran. This complete cancellation of all carbofuran registrations was finalised in December 2010. The PMRA cited unacceptable risks to human health and to the environment and stated that these risks could not be mitigated.

Chapter 2 provided a discussion of the diagnosis and forensic aspects of kills caused by carbofuran. Most of the documents referenced in the present chapter report cholinesterase inhibition levels in brain and residues in gastrointestinal tracts of casualties. Our emphasis is also on birds, however, several of the studies reviewed, especially some of the industry-led studies, also report incidental kills of mammals, reptiles and amphibians. We caution the reader that the information that follows has been collated from a very large body of incident reports which vary tremendously both in quality and detail. To ensure full disclosure and minimise confusion, we have tried to include specific information such as number of deaths, species, and residue levels detected, or even whether or not samples were analysed for residues where those were not reported.

8.2 Impacts from the sandcore (silica) granular formulations

The evidence that granular carbofuran causes extensive wildlife mortality comes from supervised field trials, various monitoring efforts (e.g., in Virginia and California) and kill incidents usually reported by farmers and members of the public.

8.2.1 Supervised field trials and surveillance exercises

Field trials under experimental control usually offer better evidence than kill reports because the investigators (1) strictly monitor the pesticide applications and (2) report carcass search efforts and other critical parameters to help identify sources of bias. The principal disadvantage of field studies, especially those that rely on finding carcasses, is that the studies often have a low power of problem detection (Mineau and Collins 1988). However, investigators usually do find dead birds, even in poorly designed studies of granular carbofuran. FMC contracted three studies (FMC 1983; 1986a; 1986b) to fulfill requirements for re-registration of the product in the United States. Balcomb, Bowen, Wright et al. (1984) conducted an additional study to confirm the

findings of the FMC study. A study by Overgaard, Walsh, Hertel et al. (1983) deals with a non-agricultural use pattern but nevertheless offers some useful insight. These reports contain substantial information that we briefly outline below.

Although investigators conducted most of these studies in cornfields, results are representative of other types of crops. As farmers typically apply granular carbofuran to bare fields, there is little to distinguish a cornfield from a potato field or any other type of field immediately after planting. Thus, the remaining variables are the number of granules accessible to birds and the presence of birds in the field. Data reviewed by Mineau and Clark (2008), as well as the kill record, indicate that the exact soil incorporation rate of granular carbofuran may be largely inconsequential. This is due to the extreme toxicity of carbofuran (see Chapter 2) and the fact that there seem to be surplus surface granules in and around treated fields, regardless of the crop or cropping conditions. The data consistently indicate that the principal determinant of a bird kill is the presence of birds in treated fields rather than the number of granules applied.

8.2.1.2 FMC 1983: corn, Utah, incorporated band application

The applicators banded Furadan 10G and 15G in cornfields (maize) at 340 g/100 m of row (FMC 1983). This application rate in corn, although registered in the United States at the time, was higher than the average rate used by farmers. The applicators then incorporated the banded granules into the soil following label recommendations, taking care to avoid spillage while loading or exposure of granules at row-ends during turning. Applicators planted three plots totalling 45 hectares with Furadan 10G. Field personnel picked up 373 dead birds of eight species during the 60-day monitoring period. Personnel picked up 504 more carcasses on nearby plots (57 hectares) treated with Furadan 15G. Personnel also collected 35 more birds that moved to control plots before dying. The overall kill rate was not statistically different between the 10G and 15G plots, but the spatial proximity of the plots meant that birds could readily move among plots before dying. Most of the dead birds were horned larks (*Eremophila alpestris*) (799 individuals killed), which were fledging from nearby fields. Investigators found dead birds representing 14 species, including the northern harrier (*Circus cyaneus*) and short-eared owl (*Asio flammeus*), two bird of prey species.

8.2.1.3 FMC 1986a: corn, Iowa and Illinois, incorporated band application

Investigators monitored three plots treated with Furadan 10G and three plots treated with Furadan 15G in Illinois and in Iowa at 1.5 kg ai/ha (FMC 1986a). Again, the applicators took care to avoid spillage or surface exposure of granules and incorporated the granules into the soil. At the Iowa sites, investigators and company personnel took additional measures to reduce the avian hazard, even though these efforts do not reflect normal farming practices because of the extreme time and effort required. In the authors' words:

> FMC personnel witnessed the planting operations and assisted in covering spills of Furadan granules. In general, these efforts consisted of walking along end rows (where the planter was raised and lowered when turning around) and kicking soil over any spills observed. At one site, the FMC representative systematically searched all end rows for exposed granules. As instructed by the FMC representative, the farmer disked [note from the authors: a tillage implement] the end rows after planting the long rows and then planted the end rows. In addition, he was asked to place a plastic flag at locations where he stopped in mid field during planting. These sites were subsequently inspected by the FMC representative.

Such actions are atypical for usual planting situations where farmers only have a limited time to plant their fields while soil and weather conditions are amenable.

Despite these efforts, there was still substantial bird mortality. As in the Utah study, there were no significant differences between the kill rates in the 10G and 15G plots. Carcass counts were 103 individuals of 17 species on the 69 hectares in Illinois and 29 individuals of 11 species on the 124.5 hectares in Iowa.

There are various reasons why these figures are minimum estimates of mortality. First, granule incorporation was uncharacteristically high due to the special efforts taken by FMC personnel to incorporate the granules. Second, FMC did not select sites with high bird populations. FMC chose the Iowa sites as being typical of the intensively cropped United States Corn Belt, and the nearest woodlot was more than 1.6 kilometres from any of the plots. Nesting habitat was therefore very limited for any tree-nesting species; these would therefore not frequent these specific fields. Furthermore, carcass searches were only conducted every three days. In cornfield habitats in Maryland, Balcomb (1986) found a very high disappearance rate of planted carcasses, ranging from 62 to 92% within the first 24 hours. Also, investigators on the Iowa plots confined their search to the fields themselves and not adjacent areas, whereas observations indicate that poisoned birds will reach shelter if they can (Mineau and Collins 1988). There was evidence in this study and the Utah study that some poisoned birds left the field and died elsewhere. Taken together, these factors suggest that the calculated mortality rate based on finding carcasses alone is a gross underestimate of the actual kill rate.

Mineau (2005) attempted a semi-quantitative analysis of the Iowa, Illinois and Utah studies described above. Dividing the carcass finding results between field edge and field interior and correcting the results for carcass finding rates and scavenging, he calculated rates of primary poisoning to be 3.05 birds per hectare from the Iowa study and 15.9 birds per hectare for the Illinois study. Based on the popularity of the product in the late 1970s to the mid 1980s, this represented a mortality of 17 to 91 million songbirds in US maize alone. The same calculation was not possible with the Utah study, but there was an estimated 52 dead horned larks per hectare. This estimate far exceeds normal densities for this species, indicating that the birds were drawn into the fields from surrounding habitat to feed on the granules.

8.2.1.4 FMC 1986b: corn, Florida and Texas, in-furrow application

This study (and the next one discussed, by Balcomb and colleagues) is interesting because granules were applied in-furrow (at 110 g ai/100 m of furrow) rather than banded (FMC 1986b). This application method leaves the fewest granules on the surface. However, one typically still finds many granules in turn rows and elsewhere in the field, particularly where there are irregularities in the soil such as rocks or residuals from the previous crop.

It appears that the plots chosen by FMC for this study did not attract the usual guilds of field edge birds. The Texas plots were rotated from cotton, one of the most insecticide-intensive crops, and the availability of insects for insectivorous bird species was likely very low. The Florida plots provided very poor bird habitat and, more importantly, received 30 applications of insecticide (permethrin or methomyl) during the two months after planting and carbofuran application. Despite a reportedly high scavenging rate, the Texas site had an uncorrected kill rate of 0.74 birds per hectare of planted field. An 'uncorrected' kill rate is based on the raw number of carcasses found by investigators. A 'corrected' kill rate means that the kill rate was adjusted upwards to reflect the finding and scavenging rates. This kill rate for the Texas site is within the range established from the Iowa and Illinois studies. Field personnel found 148 dead fish crows (*Corvus ossifragus*) on a Florida plot. Since the crows' gastrointestinal tracts contained no intact carbofuran granules, FMC hypothesised that the birds had been poisoned by other pesticides. EPA reviewers concluded that the lack of carcasses in the Florida plots was due to very low use of the fields by birds (US EPA 1989).

Before FMC conducted the Texas study and the Iowa and Illinois studies (see above), there were numerous reports of bird of prey deaths due to secondary exposure to carbofuran. Therefore, in these studies, FMC tried to examine the effects of granular carbofuran on bird of prey populations. However, EPA largely discredited these portions of the studies on the basis of poor methodology (US EPA 1989).

8.2.1.5 Balcomb 1983, Balcomb et al. 1984b: corn, Maryland, in-furrow application

Balcomb, Bowen, Wright et al. (1984b) estimated an uncorrected kill rate of 0.13 to 0.2 birds per hectare in cornfields in Maryland after an in-furrow application of carbofuran at 1.1 kg ai/ha. However, one cannot readily compare the kill rate reported by Balcomb, Bowen, Wright et al. (1984b) with the rates from the FMC studies reviewed above. In Maryland, the total search effort was very low. Furthermore, Balcomb (1986) later reported that the rate of carcass removal by scavengers was very high at this location. Balcomb (1983) documented secondary poisoning in this study. Finally, this study provided information to assess the hazard of eating contaminated earthworms. It further showed that common grackle (*Quiscalus quiscula*) nestlings taken from a nest on the edge of a treated cornfield had carbofuran residues in their gastrointestinal tracts, presumably because their parents fed them contaminated invertebrates.

8.2.1.6 Overgaard et al. 1983, Cerezke and Holmes 1986; Pine seed orchards

In a study conducted in the United States, Overgaard, Walsh, Hertel et al. (1983) used a deep-injection mechanism (POWR-TILL™) to incorporate the granules and reported soil incorporation rates of 99.1, 99.5, 99.9, and 100% on four treated sites. The investigators used a fluorescent tracer dye applied to the granules to estimate incorporation rates. Yet, over a 5-day period post-treatment, Overgaard and colleagues recovered 96 dead and 30 moribund birds from around the treated trees. Many species died, including wood warblers (Family *Parulidae*), largely insectivorous species. Even on a study site where investigators stated that the incorporation rate was at 100%, personnel recovered three moribund birds and 12 carcasses. The species included a loggerhead shrike (*Lanius ludovicianus*), a bird of prey, that likely died of secondary poisoning.

Canadian forestry entomologists (Cerezke and Holmes 1986) also conducted research in pine seed orchards, attempting to place a very high rate (up to 30 kg ai/ha) of granules into the tree root zones. Despite the (assumed) complete incorporation of the insecticide, the investigators reported having found 15 bird carcasses from an unspecified search area.

In both studies, it is likely that the casualties uncovered granules through their foraging activities, but Overgaard, Walsh, Hertel et al. (1983) suggested they may have been poisoned by ingesting contaminated invertebrates.

8.2.1.7 The State of Virginia test of FMC's 'Avian Risk Reduction Plan' (Stinson 1991, Stinson et al. 1994)

In 1990, the Virginia Department of Game and Inland Fisheries conducted a monitoring exercise to look for bird carcasses in fields following operational use of granular carbofuran (15G) applied in-furrow following a strict series of risk mitigation measures proposed by the manufacturer. FMC personnel conducted intensive training of the applicators, provided devices to cut off the supply of granules at row ends, and designated 18 to 23 metre wide no-pesticide zones along the edges

of fields. Notwithstanding these extraordinary measures, field personnel found dead birds in 33 of 44 fields searched on ten of the 11 farms monitored. Personnel found 30 species (25 birds, four mammals and one reptile) dead or debilitated in the fields. Of the carcasses recovered in the fields, 42% were more than 18 metres from the edge of the cultivated area or in the treated area. Personnel recovered fresh carcasses up to 15 days post-application that had detectable carbofuran residues. Finding these fresh carcasses so long after application was especially significant given the observations that confirmed considerable scavenging activity. The high level of scavenging, in turn, suggests that the searchers missed many carcasses. Laboratory personnel detected carbofuran residues in the upper gastrointestinal tract of 81% of 58 birds analysed. Residue levels ranged from 0.6 ppm in a savannah sparrow (*Passerculus sandwichensis*) to 208 ppm in a white-throated sparrow (*Zonotrichia albicollis*). A third (11/32) of the samples analysed contained normal brain cholinesterase levels. The findings of normal cholinesterase levels in such a high proportion of casualties reaffirmed that thorough investigation of field incidents should be based on a 'weight of evidence approach' rather than any single factor (see Chapter 2). After this study, the State of Virginia denied registration of granular carbofuran, just ahead of a negotiated settlement between the US EPA and FMC, the manufacturer.

8.2.2 Reported incidents where the product was applied according to label directions

Given the notable amount of field data implicating granular carbofuran in bird kills, we will make only a brief summary of the kill record. One can find more details in the sources cited in this section and via other resources. Farmers and bystanders rarely detect and report bird kills, and when these kills are reported, the information recorded with the kills is often inadequate. This is exemplified by an entry in the Pesticide Incidents Monitoring System (PIMS) of the US EPA (1979):

> 00/00/71 WI [Wisconsin] In an agricultural incident carbofuran was a suspect factor in an undescribed bird kill. No conclusions about pesticide involvement were drawn from the investigation. One owl was suspected of containing residues; laboratory results were not reported.

This example is given, not to denigrate the efforts of the US EPA in compiling relevant pesticide information, but rather to point to the real difficulty involved in assembling kill information from multiple sources. We must emphasise that even in the United States and Canada, few State and provincial governments have adequate resources to detect, investigate, and document fish and wildlife kills of any type.

Similarly, many kills reported by the National Wildlife Health Laboratory (formerly part of the US Fish and Wildlife Service (US FWS), now part of the US Geological Survey, USGS) are often described as '*carbamate toxicosis suspected*' leaving the reader to ponder on the chemical involved. In a 1988 survey of 351 farmers in Québec, 5% of the individuals contacted reported having encountered bird mortality in their fields. In nine cases, farmers that were contacted volunteered the identity of the chemical responsible; three of those nine cases were carbofuran kills. All cases involved toxic rodenticides or cholinesterase-inhibiting insecticides (J.L. DesGranges, Canadian Wildlife Service, personal communication).

Kill reports are especially inadequate to deal with the diffuse mortality of breeding songbirds that is expected from the use of granular carbofuran (Mineau 1988). These birds are on territories and found at low density around agricultural fields.

Despite their repetitive nature, we will briefly review some of the documented kill incidents to: 1) confirm the experimental findings under operational conditions, 2) offer evidence for crops and situations not directly tested, and 3) provide useful supplementary data such as residue profiles in

carcasses. The reader can find a more complete list of known kills, especially those that occurred in the United States, in the US EPA Docket Office (Phone number:01-703-305-5805) (http://www.regulations.gov/search/Regs/home.html#docketDetail?R=EPA-HQ-OPP-2005-0162).

The increasing number of reported kills over time is not an indication of greater carbofuran usage. Actually, the kill reports peaked at a time when use of Furadan 10G in corn had already dropped considerably (US EPA 1989). Rather, the increase in reported kills was directly linked to the EPA's Special Review of the granular products in that country. In response to the Special Review, some (but clearly not all) State agencies became aware of the importance of reporting die-offs to the EPA. Similarly, some US FWS field personnel also learned that the EPA was actively seeking data that documented both the risks and benefits associated with granular carbofuran. It is noteworthy that few reports of kills are available relative to the large area annually treated with carbofuran. However, systematic research by FMC and others (refer back to Section 8.2.1) has conclusively shown that bird kills occurring after the use of carbofuran granules are largely unavoidable. The US FWS offered the following opinion in response to a proposal by the US EPA to grant an emergency request to reintroduce carbofuran in rice:

> The Service does not believe that granular carbofuran can be used without impacts to nontarget organisms, notably trust resources protected under the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act.

[Note from the author: The words 'trust resource' refer to a natural resource protected by federal legislation.]

(Kenneth Stansell, Acting Deputy Director, Fish and Wildlife Service, United States Department of the Interior in Letter to Jim Jones, Director, Office of Pesticide programs, US Environmental Protection Agency, 16 March 2006).

This echoed a position of the US FWS, established more than a decade earlier:

> Adverse effects to birds and other fauna associated with flowable carbofuran have been established in the laboratory, in the field, and in the courts. As with granular formulations, there are no known conditions under which flowable carbofuran can be used without resulting in unreasonable adverse effects to non-target organisms.

(Richard N. Smith, Deputy Director, Fish and Wildlife Service, United States Department of the Interior in Letter to Linda Fischer, Assistant Administrator, Office of Pesticides and Toxic Substances, US Environmental Protection Agency, 10 March 1992).

As a result of the Special Review, some farmers in the US have reported observations of mass mortality notwithstanding that FMC asked farmers to support the product (Mineau 1993). Clearly, the absolute number of incidents involving carbofuran that have come to the attention of US or Canadian authorities is only a crude gauge of the wildlife loss resulting from the use of this insecticide. Therefore, one should not consider kill reports as a quantitative measure of the number of birds killed by carbofuran. Rather, these reports provide a qualitative indication of the wide breadth of circumstances (e.g., bird species, crops and geographic areas) whereby investigators have documented die-offs. The following reports also exclude intentional misuses of carbofuran in which the evidence indicates that people used the chemical specifically to kill vertebrate 'nuisance' species. We summarise the issue of intentional misuses in a separate section of this review (refer to Section 8.6, and this subject is extensively detailed elsewhere in this book). Other cases fall into a category that one might consider to be 'technical misuses'. These are situations whereby farmers did not follow the label to the letter, although there was no obvious intent of harm on their part. For example, if a US farmer or applicator was not certified to use 'Restricted Use' products (a category

to which carbofuran belongs in the United States), then legally this use of carbofuran would be a misuse even if the farmer otherwise applied the pesticide properly. Alternatively, the planting machinery may have been used incorrectly, or it was not of the recommended type; or it may have been used correctly but still left visible granules on the surface, a label violation. A study by the Bayer Corporation (Fischer and Best 1995) showed that the presence of surface granules was linearly related to application rate, despite the use of the most up-to-date application equipment (e.g., T-band applicator). There is evidence that the ability of pesticide users to adequately follow label instructions, calibrate their machinery, and actually apply the proper rates of chemicals is extremely variable (Mineau and Clark 2008). Also, agricultural machinery is quite variable when it comes to efficiently incorporating granular formulations into soil (Mineau and Clark 2008). Indeed, if one were to take the product labels to the letter, all carbofuran applications would classify as misuses. For example, the labels for granular products used to state:

> Keep out of areas inhabited by fish, birds and wildlife as this product is highly toxic to such animal.

We separate the kills into the following groups, which reflect two different modes of granule uptake:

1) Selective uptake of granules or uptake of granules sticking to earthworms or other invertebrates, usually by small songbirds; and

2) Uptake of granules and drinking of contaminated water from puddles or flooded areas. Waterfowl are often implicated, although any bird is potentially at risk. The larger body size of waterfowl species makes them easier to find.

8.2.2.1 Kills resulting from selective granule uptake

Available data indicate that most kills associated with selective granule uptake occurred in treated cornfields. This does not reflect a higher inherent risk from carbofuran in corn, but rather the total area planted to corn relative to other crops in the United States and in Canada. The labeled application rate (in grams ai/ha) for corn is similar in both countries.

8.2.2.1.2 1972–1973, corn, Wisconsin

According to Hickey (1976), growers began reporting dead sparrows soon after the US EPA registered carbofuran for use on corn rootworm (Family *Chrysomelidae*), but those reports quickly diminished. This suggests that farmers may have come to consider these kills as a ‘normal’ consequence of carbofuran use. In our many years of investigating die-offs related to carbofuran, we have often encountered people who consider that a government registration of the pesticide indicates that it is ‘safe’.

Kleinert (1974) reported results from cursory surveys of 77 fields treated with Furadan 10G, either as an incorporated band or in-furrow. This type of low-intensity survey generally has a very low power to detect carcasses (Mineau and Collins 1988). Nevertheless, the field personnel recovered 13 dead songbirds and four dead small mammals (identified only as ‘field mice’).

8.2.2.1.3 21 May 1979, corn, New York

Ten American robins (*Turdus migratorius*) were found on the edge of a freshly planted cornfield treated with granular carbofuran. Some robin tissue (the report does not specify if from a pooled sample or a single bird) contained 10 ppm carbofuran in the gastrointestinal tract and 1 ppm in the liver (Kinsinger and Lusskin 1980; Stone 1981, 1985).

8.2.2.1.4 April 1980, corn, Ludowici, Georgia

This incident provided evidence that birds can be poisoned by eating contaminated insects. Four cattle egrets (*Bubulcus ibis*) died and another was found moribund in a freshly planted cornfield. The stomach contents of the birds contained mole crickets and a few bottle fly larvae, and a pooled analysis yielded 43.1 ppm carbofuran (Davidson and Steiner 1980a, 1980b; Kirkland 1989).

It is unlikely that birds as large as cattle egrets would pick up granules directly. The granules may instead have been adhering to the insects. Alternatively, the egrets may have been scavenging other carcasses (this would explain the fly larvae). The Balcomb, Bowen, Wright et al. study (1984b, reviewed previously in Section 8.2.1.5) demonstrated the hazard from earthworms contaminated with carbofuran granules. (Another noteworthy case occurred in Switzerland where large numbers of buzzards (*Buteo buteo*) and kites, including the threatened red kite (*Milvus milvus*) were poisoned in fodder and sugar beet fields by ingesting earthworms contaminated with carbofuran – Dietrich et al. 1995). This may also be the case for other invertebrates.

Kirkland (1989) also mentioned a kill of chipping sparrows (*Spizella passerina*) under similar circumstances in 1977, but he provided no further details.

8.2.2.1.5 May 1983, corn, Shelby, New York

Twenty wood ducks (*Aix sponsa*), one mallard (*Anas platyrhynchos*), two killdeer (*Charadrius vociferus*), one blue jay (*Cyanocitta cristata*), and one common grackle were found in a field treated with Furadan 15G. A complicating factor in this case is that the seed corn was coated with diazinon, which *was* legal. The birds contained residues of both chemicals, which made it difficult for the investigators to ascertain the relative contribution of each pesticide (Stone and Gradoni 1985).

8.2.2.1.6 September 1986, turnip and Lobok radishes, Richmond, British Columbia

Based on crude carcass searches and uncorrected rates, Edwards (1986) estimated that between 500 and 1 178 birds died in this incident. Most were savannah sparrows, but field personnel also recovered some Lincoln's Sparrows (*Melospiza lincolnii*). Personnel found birds throughout fields planted to turnips or radishes. At the time, Furadan was registered for use on turnips but not radishes; hence the latter was technically a misuse. Two pooled gut contents from the birds tested negative for organophosphates but contained carbofuran levels of 26 ppm and 14 ppm. The turnips and radishes also had carbofuran residues.

8.2.2.1.7 July 1987, green peppers, Marlboro, New Jersey

The lower acreage of some vegetable crops reduces the likelihood of finding and reporting kills occurring in these 'minor' crops. Nonetheless, some documented kills have been associated with these crops. In one incident, field personnel found seven dead house finches (*Carpodacus mexicanus*) in a pepper field treated with Furadan 15G. All stomach samples submitted tested positive for carbofuran. The birds had been feeding on weed seeds on the edge of the field (Stansley 1987).

8.2.2.1.8 May 1989, corn, North Garden, Virginia

Twelve songbirds of several species were exposed in a field planted with Furadan 15G and flew to a neighbour's yard, where they were found. Several were still alive, but immoblised. Residues of 70.3, 16.4 and 19.3 ppm were detected in the gizzards (part of the digestive tract) of two respective robins and a chipping sparrow. In three of the birds analysed, brain cholinesterase inhibition ranged from non-detectable to 74% inhibition (Chudoba 1989; Hayes 1989).

8.2.2.1.9 March 1990, potatoes, Modest Town, Virginia

A farmer treated his potatoes with Furadan 15G applied in-furrow at 2.5 kg ai/ha. A neighbour subsequently reported dead birds on his land. Field investigators later found 25 dead grackles in the potato field. The investigators noted that the planter had left some potato seeds and granules uncovered

at the ends of the rows (Christian 1990a, 1990b). An investigation by the Virginia Department of Agriculture and Consumer Services established that the farmer had not misused the pesticide, although the agency recommended that, in future, he should be more diligent in covering up poorly placed potatoes and granules (Walls 1990).

8.2.2.1.10 April 1990, corn, Essex County, Virginia
This kill is highly significant and the account of it particularly compelling because: 1) the farmer applied Furadan 15G at less than half the usual rate (0.5 kg ai/ha); 2) the farmer applied the granules in-furrow, therefore giving the best possible incorporation of the product; and 3) one of the authors of this chapter (L. Lyons) and other natural resource personnel who were familiar with carbofuran participated in the field investigation. She was able to provide insightful information on the distribution of carcasses and other relevant features of the field. Notable in her observations was an absence of obvious granule spills (i.e., the farmer had thoroughly incorporated the pesticide into the soil) and that the investigators found dead birds throughout the entire field area, often as far as 30 to 50 metres from a field edge.

The significance of this finding was twofold. First, it confirmed that some birds do make use of the centre-field areas. Field margins are generally more important during the breeding season when the parent birds are especially motivated to limit their time away from the nest while foraging. However, many of the applications of granulars at seeding occur before there is much in the way of nesting activity and while there are migrants still present on the fields. Our personal observations reveal that migrants are just as likely to land anywhere in the field that appeals to them. In addition, some birds (e.g., cattle egrets and various gull species) follow the planter to catch invertebrates that are tilled up or flushed up by the tractor. Although more difficult to observe, it is likely that smaller birds such as sparrows or buntings can be similarly drawn to farm machinery.

A second conclusion derived from the field-wide distribution of carcasses is that the problem was not merely spillage of granules at row ends, but incomplete incorporation throughout the length of the furrows. Field investigators found more than 200 dead birds in this incident, excluding feather-spots (i.e., partially scavenged carcasses, with remains mostly consisting of feathers) and moribund individuals. A jogger who happened to be running by the field reported the kill.

8.2.2.1.11 July 1990, corn, several counties in Iowa
Fite, Randall, Young et al. (2006) tabulated five separate kills reported following the aerial application of granular carbofuran. These applications, which relied on the premise that granules would fall in the whorls of the corn plants, were allowed in the US at the time although they clearly resulted in substantial exposure of pesticide granules on the soil surface. Observers reported several dozens of birds of many species including not just the usual seed eaters (sparrows, blackbirds etc . . .) but also insectivores (e.g., house wren (*Troglodytes aedon)*, common yellowthroat (*Geothlypis trichas)*, brown thrasher (*Toxostoma rufum*) and even a downy woodpecker (*Picoides pubescens*).

8.2.2.1.12 February 1992, corn, Hidalgo County, Texas
In 1991, the US EPA reached an agreement with FMC Corporation that would lead to a voluntary phaseout of most uses of the granular formulations. The agreement would only allow the sale of 1 100 kg of product on a few minor crops including bananas in Hawaii, cucurbit crops (e.g., melons and cucumbers), pine seedlings and spinach grown for seed production. Because this was a 'voluntary' change, the manufacturer did not have to suffer the bad publicity associated with a product cancellation.

The agreement allowed growers to continue using existing stock and incidents therefore continued to be reported beyond the settlement date. Fite, Randall, Young et al. (2006) reported that 100 cattle egrets were found dead following an in-furrow application. Investigators determined

that the application was properly done; the birds were apparently consuming the seeds in the furrows. Carcasses were reported to contain (unspecified) carbofuran residues.

8.2.2.1.13 March 1992, corn, Brunswick County, North Carolina
Similarly, when a citizen reported 40 to 50 dead and disabled birds in her yard, which was adjacent to a small (7 hectare) corn field, investigators were called in (Augspurger, Smith, Meteyer et al. 1996). Over the course of the next two days, they found another 23 birds including red-winged blackbirds, eastern bluebirds (*Sialia sialis*), American robins, and an unidentified finch. There also, they concluded that the product had been used properly.

8.2.2.2 Kills associated with puddling of fields after application

Puddling in treated fields represents a different type of hazard inherent in carbofuran granules. Typically, the farmer applies the granules at seeding. During the spring and summer, and even during the following autumn and winter, puddles may form in the fields or the fields may even flood completely. At that point, the fields become attractive foraging sites for waterfowl and other birds. It is unlikely that waterfowl selectively pick up single granules from the soil surface. Rather, given their body size and bill morphology, it is more likely that birds inadvertently ingest granules as they sift through sediments or while ingesting contaminated water and crop residues. Dermal exposure from contaminated puddles is also possible based on existing research which concluded that dermal exposure from pesticide sprays was more important than dietary exposure (Driver, Ligotke, Van Voris et al. 1991).

At issue is the length of time that a hazard remains after the application of the granules. Wilson and colleagues (2002) verified what had long been suspected, namely that under some field conditions (e.g., acidic soils with pH below 6) several granular insecticides were quite persistent. Carbofuran was the most persistent, with half-lives of 129 and 97 days in silt loam and muck soils, respectively. Base-catalysed hydrolysis is the most important chemical degradation pathway for carbofuran (reviewed in NRCC 1979). The half-life of carbofuran in water due to hydrolysis alone ranged from 0.2 days at pH 9.5 to 1 700 days at pH 5.2. Some scientists have postulated that microbial action also aids in breakdown of granular carbofuran in flooded soil situations, but this may only be the case if the soils are neutral or alkaline (reviewed in Trotter, Kent and Wong 1989, and see Chapters 1 and 3).

Before the Wilson (2002) study reported above, Williams, Brown and Whitehead (1976) had shown a buildup of residues in Fraser Valley (BC) soils (pH of 5.3 to 5.6) after two years of use. Ahmad, Walgenbach, Sutter et al. (1979) calculated a half-life of 60 to 75 days for Furadan 10G and 11 to 13 days for the technical grade at pH 6.5. Caro, Freeman, Glotfelty et al. (1973) estimated a 117 day half-life for a Furadan 10G formulation applied in-furrow in silt loam of pH 5.2. In a kill incident reported below (in 8.2.2.2.2), 10G granules retained almost half of their initial carbofuran concentration seven to eight months after weathering in the fields. FMC (1976b) indicated that granules still contained 6.33% carbofuran (the nominal concentration of Furadan 10G is 10%) three months after exposure to soil from the Reifel Refuge in the Fraser Delta. It is therefore not surprising that the kill record reflects a long period of time between applications of the granules and kills. Despite the known extreme persistence of carbofuran under acidic conditions, we are unaware of any investigation into increased residue levels in agricultural produce as a result, although this would seem warranted.

8.2.2.2.1 December 1973, turnip, Richmond, British Columbia
Investigators found between 50 and 60 dead northern pintails (*Anas acuta*) and mallards in a partly flooded field along the Fraser River. A water sample collected from a puddle and a soil sample contained 1.7 and 1.96 ppm carbofuran, respectively (Whitehead 1975a).

8.2.2.2.2 November 1974 to January 1975, turnip, Ladner, British Columbia

Heavy rains flooded about a tenth of a field near the river (Ladner is on the opposite shore of the Fraser from Richmond). Field personnel found about 50 dead ducks of four species (mallards, northern pintails, American wigeon (*Anas americana*), and green-winged teal (*Anas crecca*)) in and around the flooded area. In a later visit to the same site about one month later, field personnel found another 15 to 20 ducks and a glaucous-winged gull (*Larus glaucescens*). Personnel recovered ten more ducks on a third visit, for a total of about 80 birds.

Although the site was a harvested potato field, there was also a row of immature cabbage on one side of the field. The farmer stated that he had planted the field to turnips the previous April or May and he used carbofuran at that time, applying the pesticide in band (with a Gandy™ seeder). After unseasonal spring rains caused crop failure, the farmer ploughed the entire field and put in potatoes. In September the farmer harvested the potatoes and planted the row of cabbage.

Field personnel found the second group of birds in a flooded section of the cabbage row. Water samples taken from the main puddle contained 0.063 ppm carbofuran. Soil sample pH values ranged from 5.3 to 5.6. Laboratory personnel found granules in the guts of one of the two birds submitted for analysis. Two laboratories analysed combined organs (heart, liver, gizzard, and intestines) from one bird. One laboratory reported a value of 60.9 ppm carbofuran, whereas another reported 8.2 ppm for the same sample. (It is possible that some degradation could have taken place in transit from one laboratory to the other but this does represent a large discrepancy.) A sample of granules taken from the field contained 4.3% carbofuran, or slightly less than half of the nominal 10% concentration, and this following about seven to eight months of weathering.

There was some confusion as to the acreage actually planted to turnips, and certain questions remained about the pesticide application rate. Also, investigators found some jugs of Furadan 4F on site that may have been used on the potato crop. However, the presence of carbofuran granules in the ducks and the residue levels left in the granules at the time of the kill suggest that the early summer application of the granular formulation was a more likely cause of death, since this is when birds would have fed on them (Whitehead 1975a; FMC 1975a; Bruns 1975).

8.2.2.2.3 October to December 1975, turnip, Ladner, British Columbia

This kill occurred in a field next to (and owned by the same grower as) the field in which the kill reported above (Section 8.2.2.2.2) occurred. Here, approximately 60 green-winged teal found initially had granules in their gastrointestinal tracts. Field crews installed propane exploders to keep other birds out of the field. A month after discovery of the first dead birds, the propane exploders malfunctioned, and about 1 000 teal entered the field and died within a few hours. Five teal examined contained between 2 and 125 carbofuran granules in their guts.

The grower had applied granules to transplanted turnips in late May through early June. This individual applied the granules around the plants by hand rather than with a calibrated applicator, as he had in other fields. The farmer harvested the crop in mid-July and later disked part of the field. (Disking is a type of ploughing; it has the effect of covering surface soil). Puddles appeared in the field in October after heavy rains. Based on the number of granules still present in the field and on residue levels found in the leftover turnips, field investigators determined that the grower had over-applied the product by a factor of two to four (2:4). The grower had also applied the granules to a nearby cabbage field, where investigators found 40 more ducks and a hawk (species unspecified). Furadan 10G was (and is) not registered for cabbage. The grower had banded the granules as in a turnip crop but, for all these reasons, pesticide regulatory authorities deemed the application a technical misuse and fined the grower under the Pest Control Products Act.

After this incident, FMC and Chemagro (the name of the Bayer Corporation in Canada at the time) withdrew registrations of Furadan 10G from the lower mainland of British Columbia (Whitehead 1975b; FMC 1975b, 1976b). At the request of British Columbia's Department of Agriculture

(P. McMullen, Chemagro, personal communication), the sale of Furadan resumed in the lower mainland in 1986. The kills resumed a short time later.

8.2.2.2.4 1977, turnip, Fraser Valley, British Columbia
About 50 ducks were found in this incident (NRCC 1979). Few details are available, except that this die-off followed the usual pattern we have described in previous case studies (P.A. Whitehead, Canadian Wildlife Service, personal communication). In view of the voluntary withdrawal in effect on the product, authorities assumed that the kill was caused by the use of old stock.

8.2.2.2.5 Autumn 1986/winter 1987, turnip, Richmond, British Columbia
Immediately after the reintroduction of granular Furadan to the lower mainland of British Columbia, there was a large kill of savannah and Lincoln's sparrows (refer back to 8.2.2.1.6). In the same field, investigators found badly decayed duck carcasses in the late autumn and winter after the kill. There was some question as to whether the kills were the result of the 5G or 10G formulation because the farmer had purchased both products. Investigators did not try to do a formal survey of waterfowl carcasses for this incident (P.A. Whitehead, Canadian Wildlife Service, personal communication).

8.2.2.2.6 Autumn 1989/winter 1990, Richmond and area, British Columbia
Bystanders turned in approximately ten bald eagles and red-tailed hawks (*Buteo jamaicensis*) to a bird of prey rehabilitation centre; these birds contained duck and gull remains. No waterfowl kill was officially reported to authorities that winter, suggesting, again, that only a small proportion of kills is ever reported. (Section 8.5 on secondary poisonings provides further detail on this incident.)

8.2.2.2.7 April/May 1990, corn, Smyrna, Delaware
In the Smyrna incident, a farmer applied Furadan 15G to corn in-furrow at 1.3 kg ai/ha. The investigator found that the equipment was new, in good working order, and properly calibrated. Ironically, FMC Corp had featured the farmer in a training video on the proper application of granular Furadan. The farmer noted that snow geese (*Anser caerulescens*) were foraging in the field on the day of application. About 2.5 centimetres of rain fell on the evening after application, producing two or three pockets of water in low-lying areas. The next day, the farmer observed some convulsing birds in the field and subsequently contacted wildlife authorities. The field investigator collected 34 snow geese, seven ducks (mallards and green-winged teal), and one laughing gull (*Larus atricilla*) and also found dead earthworms and frogs in the furrows. During a second visit a few days later, the investigating officer found three more dead ducks and more dead frogs.

A similar incident occurred in another cornfield a few kilometres away. Again, the application was in-furrow. At least four mallards died in that field and there were dead earthworms in the furrows. The investigating officer could see no evidence of any granules having been left on the soil surface (Kuncir 1990).

These incidents illustrate that water bird mortality after puddling in fields treated with granular carbofuran is not restricted to the acidic organic soils of the lower mainland of British Columbia. There are many reported kills associated with the use of granular carbofuran in rice (refer to Section 8.2.2.2.9). Furthermore, some waterfowl mortality incidents caused by granular carbofuran used in corn have come to light as a result of the US EPA Special Review.

8.2.2.2.8 January 1990, corn, Twitchell Island, California
Investigators found an estimated 155 dead ducks and geese, one red-tailed hawk, and four northern harriers in a flooded cornfield. One duck's gizzard contained 17 ppm carbofuran and two pieces of corn. One harrier had the remains of a songbird in its stomach. The songbird's gizzard content contained 3.9 ppm carbofuran.

A farmer had treated the cornfield with Furadan 10G the previous May or early June. The field had been flooded in sections in December and January to allow duck hunting. The farmer loaded the planter at the opposite end of the field from where most of the dead birds were found and unloaded the planter once back at the farm. Thus, there was no indication of likely spills at the kill site, nor was there evidence of careless use of the pesticide. Here it seems that the pesticide was sufficiently toxic to kill the waterfowl and subsequently cause poisoning via secondary exposure after seven months of weathering in the field. The investigators did not report the pH of the soil (California Department of Fish and Game (CDFG) 1990a; Otsuji 1990).

8.2.2.2.9 Rice, California

Between 1984 and 1991, 31 kill incidents associated with the use of Furadan 5G were documented in California rice fields. Field investigators recovered about 2 510 birds, mostly waterfowl but also galliform species (e.g., American coot (*Fulica americana*)) and several bird of prey species (four red-tailed hawks and one northern harrier), in those incidents (CDFG 1984a-c; CDFG 1985a-i; CDFG 1986a-g; CDFG 1987; CDFG 1988a-c; CDFG 1989a-e; CDFG 1990c; CDFG 1990d; CDFG 1990k). A single incident in 1989 resulted in the loss of at least 1 700 waterfowl (CDFG 1989c). Littrell (1988) presented 42 analyses of bird crop contents in which residue values ranged from below detection to 640 ppm carbofuran in the gastrointestinal tracts. The median observed residue level was 6.3 ppm.

At the time, the prevailing method was to apply the granules in the spring by air or ground to prepared fields, after which the fields were flooded and the pre-wetted rice seed was applied by air. Most of the mortality was recorded in the spring in freshly flooded fields. However, there were also autumn kills on record. This is significant because carbofuran was not registered for autumn use. Thus, the kills in question were either due to a long-term persistence of the granules or a misuse of the product. Littrell (1988) initially favoured misuse as an explanation of the kills, largely on the basis that granules were not believed to persist to that extent. However, granules that fell above the water line were found to persist on dry ground for several months. In autumn, fields were flooded to attract waterfowl. Authorities determined that spillage of granules during mixing and loading operations in the spring was partially responsible for the losses. Consequently, the rice industry and regulatory agencies developed and implemented a stewardship programme which included Best Management Practices (BMP) such as incorporation of granules into the soil. Since implementation of these BMPs, CDFG received only two reported incidents of bird kills after 1991 (CDFG 1993g; CDFG 1995a).

8.2.2.2.10 May 1997, spinach, Stanwood, Washingon

As noted earlier, the granular formulations were retained for the use of spinach grown for seed production following the 1991 negotiated agreement between the US EPA and the manufacturer. Fite, Randall, Young et al. (2006) report a kill of several hundred dunlins (*Calidris alpine*) in a treated spinach field. Unfortunately, no further details are provided. This is a highly interesting case because it underlies the risk of allowing dangerous registrations to persist, even in minor crops and for minor uses. The fact that the casualties are shorebirds, more commonly seen on beaches and tidal flats, makes this incident that much more intriguing. Based on the life habits of dunlins, we opted to place the incident in the section on the risk of puddling – but the association is pure conjecture at this point.

8.3 Impacts from the corncob granular formulation

Compared to the silica granule, relatively fewer studies have addressed potential repercussions with the corncob formulation. FMC conducted an extensive study in Manitoba and Saskatchewan for the Canadian Regulatory Agency.

8.3.1 Supervised field trials

8.3.1.1 Mineau 1994, Saskatchewan

A very low level monitoring exercise consisted of a single observer walking through recently seeded canola fields looking for evidence of kills where granular carbofuran had been used. The observer, who was contracted by the Canadian Wildlife Service, checked a total of 16 farms in the Saskatoon-Langham-Dalmeny area on which about 832 hectare of canola had been seeded. He chose the farms on the basis of proximity and access. Growers/field operators supplied the relevant information about planting. The observer walked the field edges and criss-crossed the fields a few times for a total aggregated search time of 78 hours. On average, the observer walked about 11 hectares per hour, with a range of nine to 13 hectares per hour depending on the field. The median time interval between seeding and searching the fields was three days (range: 1 to 5.5 days). Typically, this sort of low-level effort is insufficient to detect mortality because of the difficulty of finding carcasses (Mineau and Collins 1988).

Notwithstanding the low probability of detecting carcasses, the observer found two separate kills, and all birds collected contained carbofuran in the upper gastrointestinal tract. On one field, the observer found a dead Savannah sparrow with 37.4 ppm carbofuran, a Harris's sparrow (*Zonotrichia querula*) with 16.7 ppm, a Lincoln's sparrow with 4.5 ppm, as well as a shrew (*Sorex* sp.) with 2.9 ppm carbofuran. The observer found these mortalities in different areas of the field. In a second field, the same observer found three casualties. These birds had the following residues in their upper alimentary tract: another Lincoln's sparrow with 4.7 ppm, a white-throated sparrow with 6.8 ppm and a prairie vole (*Microtus ochrogaster*) with 20.9 ppm. Cholinesterase data also confirmed intoxication as the cause of death in most (but not all) cases. A few of the samples had spontaneously reactivated already (refer back to Chapter 2 for a more detailed discussion on this). This exercise confirmed that the granulated corncob formulation of carbofuran was broadly attractive to many bird and mammal species inhabiting or merely passing through farmland on migration.

8.3.1.2 FMC 1997, canola at seeding, Manitoba and Saskatchewan

Until 1996, all industry-funded field studies involved the sandcore granule formulation. Therefore, the Canadian regulatory authorities requested a field study with the corncob granule in order to base a registration decision. The company performed this study in the summers of 1996 and 1997, the first being a preparatory year which produced no useable data.

A technical committee including two Federal Departments (Agriculture and Environment), a provincial government representative (Saskatchewan Environment and Resource Management) and an observer from the US EPA reviewed the protocol and study results. They unanimously concluded that the specific study design was inadequate and further critiqued the registrant's approach to the data analysis. Specifically, the technical committee disagreed with FMC's interpretation of the low level of mortality in most of the treated fields (20 carcasses were found in eight fields, 11 of these were analysed and eight tested positive for carbofuran residues). FMC (1997) discounted the mortality in the treated fields because there was also mortality in control fields (five carcasses were found post-seeding, none fresh enough for analysis). However, most of this 'natural' mortality occurred on a single field and could have been caused by proximity to a road or another unexplored cause. Also, the condition of the carcasses suggested that they had been missed in pre-seeding sweeps of the area. In addition, some of these control birds could have died from treatment to other neighbouring fields; however, their deteriorated condition precluded chemical analysis.

One estimate from this study indicated a kill rate of approximately 0.9 bird per treated hectare after correcting the number of carcasses with positive carbofuran residues for field-specific finding

and scavenging rates (McKinnon in a letter to PMRA). Using three separate methods to analyse the results, the Pesticides Management Regulatory Agency concluded that the study demonstrated a kill rate ranging from 0.62 to 1.3 kills per hectare on seeded fields (PMRA 1998).

These kill rate estimates are clearly lower than those estimated from the use of the silica granular formulation. However, this study was not able to incorporate a test of the risk to large flocks of migrant birds as uncovered in one of the documented incidents (refer to the case detailed in Section 8.3.2.1). Using survey data and assumptions of the turnover rate of birds visiting treated fields, the PMRA estimated that between 27 and 100% of the birds of five different species would be killed if they landed in a treated field.

8.3.2 Reported incidents

8.3.2.1 May 1984, canola (rapeseed), Vonda, Saskatchewan

This is the first of two incidents reported for canola crops in Canada. The Canadian Wildlife Service obtained details of this incident from the investigating pathologist at the University of Saskatchewan and from the farmer who had seeded the crop. One of us (P. Mineau) estimated that more than 2 000 Lapland longspurs (*Calcarius lapponicus*) died in this incident. One notable feature of this kill was that the mixture of seeds and granules was broadcast with an air seeder and then harrowed (i.e., mechanically incorporated into the soil). According to the farmer, this was a common practice in the area, a fact that was confirmed independently (R. Atkins, Alberta Farm Machinery Institute, personal communication). Air seeders are used either to broadcast the canola seed or, alternatively, to position the seeds at a very shallow depth. In either case, the fields are then harrowed and packed.

This kill is on the record because a flock of birds landed in a freshly seeded field and, more importantly, the farmer saw the event and reported it. Even kills involving very large numbers of birds are unlikely to be reported because the birds are cryptic, the fields isolated, and the farmers are unlikely to return to the fields until the crop germinates. If growers do witness kills, they may be unaware of the importance of reporting their observations to wildlife authorities. The incident was also noteworthy in that it established the attractiveness of the Furadan CR-10 formulation to songbirds.

This incident pointed to a serious issue for Canada. Granular carbofuran was used in canola for the prophylactic control of flea beetles (Chrysomelidae, Lamb and Turnock 1982) over extensive areas of the northern prairies (between 0.37 and 0.54 million hectares yearly from 1981 to 1985; Madder and Stemeroff 1986). The peak canola seeding period is in mid-May (Alberta Agriculture 1985), which coincides with the time when the largest flocks of migrants such as Lapland longspurs traverse the prairies. Of particular concern are those species that migrate in very large flocks and use open agricultural land for foraging (e.g., horned larks, Lapland longspurs, buntings (*Emberizidae*)). There are reports of Lapland longspur flocks covering entire quarter sections (64 hectares) of the level open farmland in east-central Saskatchewan (Houston and Street 1959). Flocks of 10 000 or more birds are common (Nero 1962; Lister 1964; Hatch 1966; Houston 1971, 1972; Renaud 1973; Gollop 1986, 1987). Clearly, a few 'incidents' such as the one recorded in 1984 could have serious consequences for the populations of some of these species. Although large flocks of migrants are our main concern, there is also an ever-present risk to the locally breeding birds that frequent agricultural fields. (For another example of the risk to migrants posed by carbofuran and of the possible repercussions, the reader is referred back to Chapter 3).

A retrospective analysis by Mineau and colleagues (2005) investigated the relationship between the abundance of 29 bird species through a breeding bird survey and a granular use index for the Canadian Prairies. They found significant negative correlations for several species, suggesting that granular insecticides (primarily carbofuran but terbufos also) affected birds on a population level despite being used on a relatively small proportion of the total agricultural area.

8.3.2.2 September 1988, canola, Jeanette's Creek, Ontario

A farmer used rapeseed premixed with Furadan CR-10 as a cover crop for soil conservation, applying the seed and granules with a clover seeder starting at 09:30 and harrowing between 14:30 and 17:00 the same day. A neighbour reported the bird mortality six days later. At that time, field investigators estimated that about 200 to 300 sparrows and 'blackbirds' (mixed flocks of several species) were left on the field during the investigation (Collins 1988). The actual kill, before any carcasses were scavenged, was likely much larger. A composite sample of pooled crop contents contained 7 ppm carbofuran (Brash and Barker 1988).

Again, in this incident the farmer had broadcast the seed on the surface and then harrowed. Based on the case presented in 8.3.2.1 and available engineering research, this method of granule incorporation actually leaves fewer granules on the soil surface than some of the recommended seed drills.

8.3.2.3 May 1994, Wolseley, Saskatchewan

A homeowner found 15 dead American goldfinches (*Carduelis tristis*) while mowing the lawn. While the property was in a canola growing area, it was not clear where the birds were exposed to carbofuran. We could not rule out a spill of seed on the road as seeders are often moved from one field to another and seed might have spilled. Cholinesterase data suggested carbamate intoxication, and we verified the presence of carbofuran in two of the three samples analysed by the laboratory. (For reasons of economy, it is typical to only carry out a few residue analyses for any given incident, even in relatively affluent North America.) The pathologist reported small seed resembling canola seed in the crops of the birds. Lindane residues were also detectable in one bird, suggesting that this compound was used as a seed treatment at the same time that carbofuran granules were added to the seed, which was a usual procedure (Mineau 1994).

8.4 Impacts from the flowable (liquid) formulation

There is ample evidence linking the use of the liquid formulation of carbofuran to bird kills. This includes company studies mandated by the US EPA, other field studies (primarily in Canada), surveillance programmes and incident reports. The latter were obtained primarily from US EPA docket files but we consulted other information where relevant. We omitted cases where carbofuran had been tank-mixed with other insecticides even though we can often surmise about the relative contribution of each insecticide based on its inherent toxicity and concentration.

8.4.1 Industry-supervised field trials

The most extensive field studies available for flowable carbofuran are those conducted by the manufacturer, at the behest of the US EPA. These studies are basically carcass searches conducted in cornfields and alfalfa fields. They are briefly reviewed here. The most recent review of these same studies (as well as some of the other studies reviewed in this chapter) by the US EPA can be found in Fite, Randall, Young et al. (2006).

8.4.1.2 FMC 1983: alfalfa, Utah

FMC conducted this study concurrent with the study on corn granulars reported in Section 8.2.1.2. The results of the study were difficult to interpret because key information was missing. Also, the total carcass search effort was minimal relative to the effort needed to ascertain whether there was mortality associated with the pesticide. The US EPA, in their recent review (Fite, Randall, Young et al. 2006) similarly dismissed this study.

8.4.1.3 FMC 1989a: corn studies, Nebraska

Farmers under the direction of FMC applied Furadan 4F by air to non-irrigated fields at 1.1 kg ai/ha per application; two applications were made. Although FMC personnel carefully supervised the mixing and application, the researchers had considerable difficulty with their chemical 'accountability'. Tank samples taken directly from the spray booms immediately after spraying had recovery rates of the active ingredient ranging from 66 to 210%, except for one sample that contained 1.9% of that expected. The flowable carbofuran formulation is a suspension that is difficult to keep homogenised. The high variability in this carefully monitored field trial suggests that the amount of carbofuran deposited likely fluctuates widely under operational use conditions. One should consider this variability when evaluating residue information from field trials or reported kills. The researchers also seemed to experience problems with their analytical capability, because the recoveries of three fresh samples of formulation taken directly from the jugs the product was sold in ranged from 75 to 84%. Alternatively, this may denote problems with the quality of the product.

Spray deposit cards placed at various levels in the crop reinforced that there were difficulties in chemical accountability. Individual readings from cards placed in the crop canopies ranged from 0.18 to 100% of that expected in the eight treated fields over the course of the two applications. Average deposits from each application ranged from 6.6 to 44%, with a grand mean of 22% of that expected. Given that a deposit rate of 60% or better is considered typical of a 'successful' aerial application (Sheehan, Baril, Mineau et al. 1987), this application had poor overall coverage. Peak residues (two hours post-spray) of field edge vegetation (all four edges being pooled for any given field, with samples taken 5 metres into the edge) averaged 53.4 ± 64.3 ppm for the first application and 44.4 ± 90.4 ppm for the second. Field personnel placed drift cards about 3 metres into all four field edges. The field edge receiving the most drift (presumably the downwind edge, although the report does not specify wind conditions during application) received between 16.2 and 167% of mean deposits obtained at the top of the corn canopy (mean of 82.1%, based on 13 different applications). This extent of edge contamination after aerial application is not surprising; especially where several spray swathes (i.e., bands) contributed to the downwind spray deposition (Maybank, Yoshida and Grover 1978).

Field personnel searched the plots for seven days before the first Furadan application and for seven days after each of the two applications. The study authors used the 'pre-treatment' mortality as a covariate of post-treatment mortality. However, this was inappropriate because those plots had been treated with toxic insecticides, including ethyl parathion, between two and three weeks before the study began. Therefore, the pre-treatment mortality may have been due to pesticide poisoning rather than reflecting 'background' mortality. Also, 'pre-treatment' mortality represents the accumulation of carcasses and feather-spots over a prolonged period of time and is a poor covariate for mortality immediately following a pesticide application. Therefore, it is our view that the statistical analysis of the carcass data is likely invalid and lacking relevance. The study authors also compared the kill data with surveys of live birds conducted on the plots. Such comparison provides little to no understanding of the pesticide effect, and the authors stated that the live bird surveys were difficult to interpret because the lateness of the season meant that the bird populations were mobile and not 'tied' to the study fields.

However, as the areas searched in treated and control fields were similar and search intensities were held roughly constant, it is still meaningful to look at the overall number of carcasses found in treated versus control fields, assuming that field personnel found most of the pre-treatment carcasses over the seven days of searching. This effectively assumes that the personnel had swept clean the areas of carcasses before the application of Furadan 4F. For reasons given above, the number of carcasses found during these pre-treatment sweeps to assess natural mortality is not relevant. In other words, this study is potentially useful from a qualitative standpoint only.

Field personnel found 14 dead birds in the carbofuran-treated fields and in the edges of those fields over the 14 day period comprising the two applications. By contrast, personnel found five dead birds in the edges of the control fields. Those fields had been treated with pyrethroid insecticides (which are of low acute toxicity to birds). The authors speculated that this 'control' mortality may have been due to exposure to pesticides used on adjacent fields not under experimental control. Interestingly, at least one of the five control carcasses was from a field edge where the adjoining cornfield had been treated with carbofuran, at 75% of the experimental rate. An immobilised but living warbler was also associated with the same control plot. Furthermore, edge vegetation from all fields where carcasses were found contained detectable carbofuran residues. Therefore, all carcasses found post-treatment in this study were associated with some carbofuran use, either experimentally or incidentally.

The investigators analysed the gastrointestinal tracts and/or brains of 11 birds found dead on carbofuran-treated plots for presence of the compound. All but two birds had detectable residues. However, since field personnel collected these two birds at five and six days post-spray, chemical degradation likely accounts for the lack of detectable residues in these carcasses (further expanded on in Chapter 2).

Poor analytical recovery made detecting carbofuran residues in any carcass even more improbable. The authors looked at the persistence of residues injected into the gastrointestinal tracts of carcasses left to age in the fields and others spiked in the laboratory. Recovery of carbofuran from the gastrointestinal tracts of four birds analysed immediately (0.5 hour) after laboratory spiking ranged from 0.5 to 1.3 ppm (7.3 to 19% of that expected). Birds spiked in the field and then taken to the laboratory rarely had levels that were quantifiable (above 0.10 ppm) and levels were usually below the detection limit (less than 0.05 ppm). One may therefore conclude that finding carbofuran residues in field-recovered carcasses is a significant event (again, refer to Chapter 2). This is in sharp contrast to the long persistence of carbofuran in acid soils (on the order of months) as documented in Section 8.2.2.2.

The researchers made several observations of 'deficit behaviour', that is to say any behaviour judged to be abnormal. However, it seems that some field personnel had difficulty judging whether individuals were behaving abnormally, and certain reports lacked good descriptions of the abnormal behaviours observed. Only one type of abnormal behaviour, immobilisation of the bird, is unequivocal. This effect is typical of cholinesterase-inhibiting insecticides and less likely to be misinterpreted by a field observer. The researchers found four birds immobilsed on the Nebraska fields. Of these, one was the aforementioned warbler associated with a 'control' edge next to carbofuran use, and the other three were on carbofuran-treated plots.

Field personnel found carcasses of other animals, mostly mammals and amphibians. These carcasses were associated with both treated and control fields but were found primarily in field edges, making an interpretation difficult for reasons mentioned above. Four of seven non-bird carcasses found post-treatment and analysed had measurable quantities of carbofuran in their gastrointestinal tracts. Study authors suggested an association between carbofuran treatment and amphibian mortality after finding four southern leopard frogs (*Rana sphenocephala*) at the edge of a carbofuran-treated plot between two and six hours after application.

In all, field personnel searched an area of approximately 32 hectares, divided equally between field and edge, for carcasses in the carbofuran-treated fields. This represents an uncorrected kill rate of 0.43 birds per hectare.

8.4.1.4 FMC 1989a Texas/New Mexico pivot-irrigated field

Despite the different outward appearance of these fields (i.e., perfect circles, 800 metres in diameter) and the nature of the field edge habitat (which was concentrated in the non-cropped corners of the square fields), the methods used in this study were very similar to the methods used in the

Nebraska study, described previously in Section 8.4.1.3. Results were also similar and confirmed those obtained previously.

Again, the investigators reported serious problems of chemical accountability. The recoveries of three spray tank samples ranged from 22 to 41% of the expected amount of carbofuran active ingredient. Collection cards positioned high in the corn canopy showed mean field deposits ranging from 19 to 70% of nominal rate, with an average of 36%. These applications are somewhat better than those on the Nebraska plots (with a grand mean of 22%) but still poor from the point of view of efficacy and pest management. The report also noted considerable contamination of field edges.

Researchers found 17 dead birds in the carbofuran fields and edges post-treatment, with a roughly equal proportion in both habitats. Field personnel recorded most of this mortality within two days of a carbofuran application. This compares with two dead birds found in the control plots (one in a field, the other in a field edge). The farmer had treated the control fields in this study with dimethoate applied in cottonseed oil and with a 'control application' of a pyrethroid. We reiterate that it is meaningless to look at pre-treatment mortality given the range of pre-treatment sprays made in control and treated fields (again, ethyl parathion was used on some plots). All bird carcasses analysed for carbofuran had quantifiable residues in their gastrointestinal tracts (ranging from 0.2 to 2.4 ppm).

The researchers reported finding three immobilised birds, including one bird of prey (northern harrier) on the Texas/New Mexico plots. Two birds were found on control fields. However, there were detectable carbofuran residues in these 'control' edges. Residues in the edges of the control field with the immobilised harrier were identical to those in the edges of treated fields four days post-application (13.3 ppm).

Non-bird mortality was also interesting. Researchers found eight dead amphibians (toads, frogs, and salamander) and one mouse (Genus *Peromyscus*) on carbofuran plots post-treatment. All had quantifiable carbofuran residues in their gastrointestinal tracts, ranging from 0.1 to 9.4 ppm. Researchers also found a dead mouse (unspeciated) and a skink (a type of lizard) in the edges of control fields.

The finding of dead amphibians with high gut residue levels in these Texas study plots combined with the observation of the four dead leopard frogs associated with a carbofuran spray in the Nebraska study indicates that amphibians are at risk from carbofuran use. The researchers did not provide residue analyses for these specimens, and provided no reason for excluding these data from the report.

Given a similar search area in the Texas/New Mexico plots, about 32 hectare divided equally between field and edge, yields an uncorrected mortality rate of 0.53 birds per hectare.

Based on carcass search efficiency (where the ability of search crews to find dead birds is assessed with planted birds or decoys) and scavenger rate measures (where carcasses are placed in fields and the time it takes for them to be scavenged/removed by scavengers is measured), Mineau (2005) suggested that the true kill rates for the sprayed cornfields in the Nebraska and Texas studies were 2.4 and 2.0 carcasses per hectare respectively.

8.4.1.5 FMC 1989b: alfalfa studies, Kansas

Using the same basic design in alfalfa fields as in the corn studies previously reported (see Sections 8.4.1.2 and 8.4.1.3), researchers conducted studies in Kansas and Oklahoma. Collaborating farmers/applicators treated 16 fields (eight in each study area) twice with Furadan 4F by ground (Kansas) or by air (Oklahoma). They first applied 1.1 kg ai/ha and then half that rate about one or two months later. The design of these studies was compromised because the farmers also treated the carbofuran-treated and control fields with carbaryl or methomyl as needed and treated control fields with chlorpyrifos. Thus, of the planned eight pairs of treated–control fields in Oklahoma, only two pairs

actually received the same insecticide application. Furthermore, there were insecticide treatments (including carbofuran use) in some fields next to study plot fields, again confounding the exposure situation. Nevertheless, we provide highlights of these studies.

Due to the lag between the two treatments, there were two periods of pre-treatment carcass searches in both the Kansas and Oklahoma fields. Field personnel carried out searches for ten days before each treatment and for seven days thereafter.

Samples taken directly from the tank sprayer showed carbofuran recoveries ranging from 46 to 106% (N = 8), again suggesting poor mixing of the active ingredient in the spray solution. Residues collected on cards just above the crop canopy showed that deposits on individual plots ranged between 23 and 57% of that expected after the first application and between 1.0 and 75% of expected for the second. Grand means were 43 and 23% for the first and second sprays, respectively. These deposits are low for ground application equipment. The highest field edge deposits (presumably the downwind samples, although their location was not specified) taken three metres in from the field edge ranged from barely detectable to 14 times higher than those obtained in the fields themselves. In six of the 16 applications monitored, maximum field edge residues were higher than the average field deposit.

Field personnel found only five bird carcasses over the 20 days of pre-treatment periods in all fields, whether treated or control. However, personnel found 15 dead birds in the search areas after the two carbofuran sprays and seven after the two ‘control’ chlorpyrifos sprays. Personnel collected eight of the 15 birds found on carbofuran plots post-treatment after the second spray at the lower application rate. Searchers also found four immobilised individuals, three in carbofuran-treated plots. These included a northern harrier that was seen feeding on an eastern cottontail (a small rabbit, *Sylvilagus floridanus*) which contained 0.1 ppm of carbofuran residues. Field personnel also found non-bird carcasses in both carbofuran- and chlorpyrifos-treated plots, but only after insecticide application. Of the eight bird carcasses found in either post-treatment period on the carbofuran plots and analysed, five had detectable carbofuran in the gastrointestinal tract or brain. This is very significant in light of the aforementioned difficulty of recovering carbofuran from spiked carcasses (refer back to Section 8.4.1.3). Likewise, two of three carcasses found in either post-treatment period in the control fields contained chlorpyrifos residues. The significance of this finding is more difficult to ascertain, because the study did not include field spiking carcasses with chlorpyrifos.

It appears that both the carbofuran and chlorpyrifos treatments caused mortality in this study. The uncorrected kill rate for carbofuran was 0.47 birds per hectare.

8.4.1.6 FMC 1989b, Oklahoma fields, aerial application

This study reaffirmed the difficulty of controlling carbofuran applications. The recovery rate of samples taken from the spray tanks after application ranged from 23 to 189% of that expected (N = 6). Readings from deposition cards in the fields ranged from 8.5 to 56% of the nominal rate during the first application and from 1.2 to 47% of nominal during the second. As in the Kansas ground spraying situation, deposits were extremely low in some fields, especially for the second application. In the Kansas plots, the investigators used different types of spray cards for the two sprays; however, this was not the case in Oklahoma. The authors gave no other reasons that might explain the poor results on some plots. Grand means for all treated plots were 33% and 21% of nominal for the first and second sprays, respectively. These values are in the same range as the values reported after ground application in Kansas. Card deposits three metres into the field edge had maximum (presumably downwind) values ranging from less than 1 to 583% of field deposits. Maximum edge deposits exceeded average field deposits in nine of 16 fields monitored.

Searchers found seven bird carcasses in the post-treatment periods in the carbofuran plots compared with one bird in the pre-treatment ‘sweeps’ of the search areas. This represents an uncorrected

kill rate of 0.22 birds per hectare. Of the seven carcasses, searchers found four after the second (lighter) spray. Searchers also recovered 17 bird carcasses from the control plots treated with chlorpyrifos (compared with three in the combined pre-treatment periods). Searchers found two immobilised birds, both on chlorpyrifos-treated plots. Other carcasses, including mammals, reptiles, and amphibians, were also retrieved from both carbofuran- and chlorpyrifos-treated plots post-spray.

Of nine carcasses found post-spray on the chlorpyrifos search plots and subsequently analysed, eight contained chlorpyrifos residues in either the gastrointestinal tract or the brain. Similarly, carbofuran residues were detected in three of four carcasses analysed from the carbofuran-treated plots post-treatment.

Industry studies have clearly shown that carbofuran applied by ground or by air, at either 0.55 or 1.1 kg ai/ha onto alfalfa and adjacent field margins, kills birds and other vertebrates. The estimated bird kill rates corrected for searching and scavenging, were 1.1 and 0.61 birds per hectare for Kansas and Oklahoma fields respectively. Chlorpyrifos, an alternative to carbofuran, applied at 1.1 and 0.55 kg ai/ha, also caused bird mortality. However, the studies were inadequate for evaluating the effects of chlorpyrifos use. That is, researchers did not monitor the chlorpyrifos applications, and there is the confounding aspect that all the control fields had measurable carbofuran residues at their field edges, presumably due to spraying in neighbouring fields. The researchers did not analyse carcasses found on chlorpyrifos-treated plots for residues of carbofuran.

8.4.2 Field studies of carbofuran used as a grasshopper insecticide

Grasshopper control was a main registered use pattern of carbofuran in Canada until it was cancelled by the regulatory authorities following unacceptable impacts and risk to the burrowing owl, an endangered species. These studies stand out from the industry studies previously reported because of the extremely low application rate of carbofuran (132 g ai/ha). We believe this is the lowest rate of the product registered anywhere in the world.

8.4.2.1 Horstman 1985, Horstman and Code 1987

These studies examined the effect on nesting Brewer's blackbirds (*Euphagus cyanocephalus*) and other passerine species of carbofuran sprayed on roadside verges at the low rate of 132 g ai/ha to control grasshoppers. About 60% of the spraying was applied aerially and the remaining using ground equipment. Egg and nestling mortality rates were significantly higher in sprayed nests, principally as a result of single egg or nestling disappearances. Such a disappearance at the earlier stages of nesting suggests abandonment of the nest and/or loss (i.e., mortality) of the adults. Of eight treated nests with such disappearances, five had been sprayed with carbofuran, the others with other insecticides. Total nest abandonment was also higher in treated nests, but sample size was too small for statistical analysis. Field personnel found some dead nestlings, but these did not contain detectable residues. Horstman (1985) concluded that nestlings might be at risk from eating carbofuran-treated insects. However, she also postulated that habitat differences may have led to uneven predation rates, with untreated nests being in habitats less prone to predation.

Horstman and Code (1987) designed a study to verify Horstman's 1985 work and to add to the sample size. This was a planned study in which the investigators applied carbofuran themselves by ground rig for a distance of 0.4 kilometres along the roadside on either side of the nests. Some nests were exposed to two sprays ten days apart. The researchers only monitored Brewer's blackbirds. Unlike observations made in the previous study, the researchers noted that adult females foraged principally in the fields adjoining the road verges rather than in the verges themselves. However, Hostman and Code did not quantify the relative importance of these habitats. This time, they found

that egg survival and hatching rates did not differ between control and treated nests. Nestling mortality was significantly higher in treated nests than in control nests in one of the two site pairs only, but no dead nestlings were found. Predation was higher in treated sites, but abandonment was higher in control sites. Several nestlings sacrificed for analysis contained residues of carbofuran.

Taken together, these studies did not demonstrate any convincing effect of carbofuran at 132 g ai/ha on nesting Brewer's blackbirds. There were too few data on the other species in Horstman (1985) to reach any conclusions. The following factors limited the usefulness of these studies:

1. No grasshopper outbreak occurred during the 1987 study, and birds may therefore not have been exposed to large numbers of contaminated prey. Although the birds principally foraged in the ditches in the 1985 outbreak year, in 1987 they mainly foraged in adjoining fields.
2. During the 1987 study, it rained soon after spraying. This affected both nests in the egg stage (1.5 to 5 hours between spray and rain) and those in the nestling stage (12 to 16 hours between spray and rain). In the first case in particular, the incorporation of the insecticide into the local insect biomass may have been reduced.
3. Due to unforeseen delays, in 1987 the spray truck was filled the day before spraying. Although the water used in the truck likely was not alkaline enough to cause significant degradation of the carbofuran, it is likely that insufficient agitation caused uneven application of the insecticide (L. Horstman, personal communication). The investigators did not take samples to confirm the uniformity of the concentration of carbofuran in the spray solution.

8.4.2.2 Irvine 1987, 1990, Forsyth et al. 1989, Forsyth and Wescott 1994

These three reports and this publication summarise the available data on a large-scale experimental carbofuran spray, carried out in 1987, and a smaller application, made in 1988. Field personnel sprayed a large grazed pasture with native grasses (259 hectares) with flowable carbofuran at a low rate (140 g ai/ha). Forsyth, Jackson, Westcott et al. (1989) also established a control site for comparison. The impact work consisted of looking at small mammals and birds from the central cores of the two blocks.

Field personnel used a series of 24 randomly positioned transects monitored with spray deposition cards. Average droplet numbers ranged from one to 24 per square centimetre.

Pooled samples of dead grasshoppers collected with forceps from the same area contained average carbofuran residues of 2.1 ppm one to three hours post-spray and 2.5 ppm six to nine hours post-spray (Forsyth and Westcott 1994). Grasshoppers collected in sweep net samples (which included both living and dead grasshoppers) contained residues ranging from 0.45 to 6.6 ppm carbofuran on the day of spraying, which declined rapidly on successive days.

Residues on vegetation samples taken from 0.25 square metre quadrats averaged 13.3 ppm one to three hours post-spray and 5.9 ppm ten to 11 hours post-spray. Overall, on the spray day (18 June), vegetation samples had residues ranging from 1.1 to 21.8 ppm. On 19 June, the residues ranged from 1.2 to 21.7 ppm. A light rain (3 millimetres) fell on 19 and 20 June, likely reducing the pesticide residues on the vegetation. Samples taken on 20 June ranged from 0.1 to 1.1 ppm.

Field personnel first searched the area between eight and nine hours post-spray. They searched less than 1% (about 0.7% or 1.9 hectares) of the total spray area, over a three hour period and repeated the search 32 and approximately 150 hours post-spray. The searchers did not find any dead or moribund birds. However, the small area searched, the minimal amount of time devoted to this activity, and the breeding density (approximately four breeding pairs per hectare for all the regular bird species combined) would have made it difficult to find carcasses even if there had been mortality. Furthermore, it does not appear as if the investigators determined search efficiency or carcass disappearance rates.

Field personnel conducted three pre-treatment and three post-treatment surveys on three centrally located plots of 300 by 600 metres. The personnel also tried to find nests and collected some birds (by shooting) for cholinesterase measurement.

Two of 11 common breeding species showed a significant decline in the post-spray period relative to the pre-spray period. Although declines in those species were also seen in the control plot, they were not significant. Nest success rate was 46% (17/37) for treatment nests versus 83% (10/12) for the controls. This difference is statistically significant ($X^2 = 5.12$, $P = 0.024$). The researchers believed that most of the nest losses were due to predation. However, nest losses did not seem to peak on days one to three post-spray, when, based on the characteristics of carbofuran, one would expect to observe a toxic effect on the adults or young.

As one can best determine from the data provided, the researchers collected seven songbirds by shooting on the day of spraying (four horned larks, two red-winged blackbirds (*Agelaieus phoeniceus*), and one brown-headed cowbird (*Molothrus ater*)). Because spraying occurred over an extended period, it is impossible to determine whether the researchers collected all birds from areas already sprayed. Four of the seven exhibited a reduction in brain cholinesterase of more than 20% (three of the four horned larks and one red-winged blackbird). Maximum cholinesterase depression was 61% in the larks, and the blackbird showed a 52% reduction in activity relative to control. None of the three birds sampled one day post-spray (one red-winged blackbird, one vesper sparrow (*Pooecetes gramineus*), and one eastern kingbird (*Tyrannus tyrannus*)) exhibited brain cholinesterase depression greater than 20% (refer back to the discussion in Chapter 2).

The researchers established and ran a live-trap grid for ten nights pre-spray and seven nights post-spray and placed snap traps away from the grids to collect individual mammals. Irvine (1987) stated that there did not appear to be any day-to-day shift in the relative ratios of new to recaptured animals during the post-spray period. However, the data presentation does not allow one to look specifically at the survival of animals marked before the spray in the post-spray period. Also, inconsistencies between the tabular data and a figure preclude meaningful interpretation. The populations studied appear to show a very high rate of turnover in both the pre-spray and post-spray periods. Despite ten consecutive nights of trapping, recapture numbers remained consistently below the number of new captures for most of the pre-spray period.

The researchers snap-trapped only one deer mouse (*Peromyscus maniculatus*) on the night after the spray, and it had a brain cholinesterase inhibition level of about 45% relative to control. The researchers sampled three more small mammals about one week post-spray. One sagebrush vole (*Lagurus curtatus*) exhibited a low cholinesterase level, but not to the extent of being diagnostic.

8.4.2.3 Fox et al. 1989

At the time of this study, burrowing owls were officially listed as 'threatened in Canada'; their status has now been upgraded to 'endangered'. In 1986 and 1987, the Canadian Wildlife Service commissioned fieldwork to investigate the impacts of operational grasshopper spraying on the species. The following summary is from the final report by Fox, Mineau, Collins et al. (1989) that outlined the research and resulting analyses in great detail.

The data of Fox and colleagues showed conclusively that, in 1986, carbofuran applied at 132 g ai/ha had a significant impact on the survival and reproductive success of burrowing owls. There were significant declines in nesting success (P = 0.002) and brood size (P = 0.006) with increasing proximity of carbofuran spraying to the nest burrow. In this case, Fox, Mineau, Collins et al. (1989) defined nest success as the proportion of burrows that fledged at least one young. No trend of lowered reproductive indices with increasing proximity of spray was observed either for the insecticide carbaryl or for all insecticides other than carbofuran pooled together. Overspraying of the burrows with carbofuran caused an 83% reduction in brood size and an 82% reduction in nesting

success. Of 12 pairs of birds exposed to an overspray, eight nests failed completely. In contrast, only two of 14 burrows sprayed with carbaryl exhibited complete nest failure. During a telephone interview conducted after the study, two landowners reported complete disappearance of owls after a carbofuran overspray (three and eight burrows affected, respectively) at colonies that were outside the study area. Burrow reoccupancy in 1987 was less frequent after the 1986 use of carbofuran than after the use of other insecticides.

The significance of these findings is increased when one considers that the researchers did not direct or control any of the spraying, in other words they collected the data from an *a posteriori* study design. In addition, the statistical analysis was very conservative, in that it allowed for possible biases among owl colonies, such as a farm effect, even though no such biases were documented.

The impact on nest success was related to distance of the spraying from the burrow. There was some indication that spray events occurring even at more than 50 metres from a burrow were also detrimental to reproductive success ($0.05 < P < 0.1$). These data further suggest that the effect of carbofuran was due to toxicity rather than food removal. Another insecticide, notably carbaryl, did not appear to affect owl reproduction despite its removal of insect food. There were too few data to be certain about the safety of a third insecticide in use, chlorpyrifos.

In response to these study results, the Canadian Regulatory Authorities initially tried to limit the risk to burrowing owls through labelling restrictions and farmer education although there is evidence that these attempts were largely ineffective (Trowsdale Mutafov 1992; Mineau 1993). They cancelled several uses of the liquid formulation in 1995 in order to completely eliminate exposure to burrowing owls.

8.4.2.4 Brusnyk and Westworth 1987

Birds are the focus of most directed field studies because of the taxa's extreme sensitivity to carbofuran. Consequently, the finding of other vertebrate wildlife is often considered incidental. This study is an exception in that the researchers studied only small mammals.

Brusnyk and Westworth chose two study sites, a dry pasture and another site with high interspersion of wetlands. They established one control and one treated plot on each site, and used a ground sprayer to apply carbofuran at 132 g ai/ha to the treated plot. The investigators did not provide the size of the sprayed plots or any measure of pesticide deposit.

The researchers live-trapped small mammals for six consecutive days pre-spray and three consecutive days post-spray. They also conducted late-season trapping about five weeks post-spray. The researchers collected some individuals between 16 and 20 hours post-spray for brain cholinesterase assays.

Meadow vole (*Microtus pennsylvanicus*) numbers decreased in both habitats after the spray, although the authors considered the decline significant only in the pasture habitat, where numbers fell by about 85%. It appears that the investigators did not analyse these data statistically, and the basis for rejecting the vole decline in the wetland habitat is therefore unclear. In contrast, total numbers of deer mice remained constant post-spray.

Turnover rates of marked individuals on both treated and control plots were high, and survival rates were based on small numbers of recaptured individuals. Survival, defined as the proportion of marked animals recaptured, was much lower for young deer mice and for all voles in treated plots. Survival of adult deer mice did not appear to be affected. However, in post-spray plots the researchers found a significantly higher proportion of male deer mice in non-reproductive status relative to expected numbers from the control plots.

Mean brain cholinesterase levels in collected deer mice did not differ significantly between control and treated plots, but there was evidence that some (males especially) were exposed to carbofuran based on the variances in the mean brain cholinesterase levels reported ($F = 18.65$, $df = 15$, $P < 0.05$). The authors did not provide individual data to substantiate this.

A pooled sample of gastrointestinal tracts from 20 deer mice contained 2 ppm carbofuran. The researchers did not prepare field spikes nor did they verify the recovery of carbofuran from mouse tissue in the laboratory.

Despite several important deficiencies in this study, some interesting observations emerge. Voles are almost totally herbivorous while deer mice are more insectivorous. Consequently, one would expect voles to be more susceptible to carbofuran poisoning than deer mice, though the former may eat poisoned insects. There was a precipitous reduction in the vole population on one of the spray sites, and calculated ‘survival rates’ were lower on the treated plots combined for that species. Although overall numbers of deer mice did not change post-spray, there was a significantly higher turnover rate of young individuals on treated plots, indicating higher death or emigration from those plots. Insufficient details were provided to properly assess the cholinesterase data. In any case, it is likely that these data are biased, because severely intoxicated animals are likely to be less mobile and have a lower trappability.

The relatively high residue level measured in the deer mice (2 ppm in gastrointestinal tracts) is cause for concern. It was hypothesised in the study on burrowing owls (reported in 8.4.2.3) that small mammals might provide a source of residues for the owls. Some birds of prey feed extensively on these populations of small mammals. Given the results of the research and probable routes of exposure, it is likely that the voles would have shown higher residue values than the deer mice. Furthermore, small mammals may also acquire substantial residues on the surface of their fur as they forage in treated crops, but this was not measured. In FMC research documented earlier (refer back to Section 8.4.1.5), field personnel found a paralysed northern harrier after it fed on a cottontail rabbit with 0.1 ppm total body residues. The authors of the current study did not provide the information necessary to convert the 2 ppm of residues in the pool of gastrointestinal tracts to whole body burdens.

8.4.2.5 Martin et al. 2000

The authors of this excellently designed and executed study followed two species of nesting songbirds (chestnut-collared longspurs (*Calcarius ornatus*) and Baird’s sparrow (*Ammodramus bairdii*)) on 56 hectare plots aerially sprayed with 132 g ai of carbofuran. The bulk of the data was collected on the longspurs. Breeding parameters, namely number of eggs, nestlings and fledgings per nest were not affected by spraying. Despite demonstrated brain cholinesterase depression in nestlings as high as 70%, the data showed at most a 17% reduction in individual nestling success in nests that survived predation. However, the number of productive Baird sparrow territories was significantly reduced in the Furadan-sprayed plots. The authors speculated that this species might be more toxicologically susceptible to carbofuran but numbers were low and conclusions remained tentative.

8.4.3 Monitoring programmes in US cotton

Several US States attempted to monitor the application of carbofuran to cotton fields at the rate of 280 g ai/ha (Fite, Randall, Young et al. 2006). The only indication of effects came from a California monitoring programme where searchers found seven fox sparrow (*Passerella iliaca*) carcasses as well as a ground squirrel (Family Sciuridae) in a field adjacent to a carbofuran-treated field. The finding of so many dead birds of the same species argues for this to be pesticide-related, but there was not enough tissue available for analysis. Other monitoring efforts did not turn up any evidence of effects but the US EPA severely criticised these efforts as generally inadequate and lacking in key components of adequate carcass searching practices. A more complete review can be found in Fite, Randall, Young et al. (2006).

In at least one application, workers became ill after re-entering the field on the day of spraying. As argued by the US EPA (Fite, Randall, Young et al. 2006), it is inconceivable that foraging birds should not be at risk from these applications when 150 pound mammals (i.e., people) with a much lower sensitivity to the chemical are at risk of serious effects by merely entering those same fields.

8.4.4 Incidents

8.4.4.1 Incidents where birds were killed from grazing on treated vegetation

Birds that graze on freshly-treated vegetation are always in a high exposure situation. Observers have reported grazing-related mortality of waterfowl and other species associated with several organophosphorous and carbamates of high toxicity (Mineau 2003). Given its extreme toxicity to waterfowl (as discussed in Chapter 2), it is not surprising that carbofuran has frequently been associated with kills of grazing waterfowl. FMC also acknowledges the toxicity of their products to waterfowl. For example, in the United States, labels for Furadan 4F had the following requirements:

- do not apply before or during furrow irrigation;
- do not apply on fields in proximity of waterfowl nesting areas; and
- do not apply on fields where waterfowl are known to repeatedly feed

The State of California (where there have been many waterfowl kills) treats any deviation from the above as a misuse of the product subject to prosecution. Therefore, the State of California considers some of the kills reported here as technical misuses, putting the responsibility on the growers to be aware of waterfowl feeding patterns in their areas. We note that California defines 'in proximity' as one mile (1.6 kilometres) (Betts 1975).

Due to the small size of young waterfowl and the secretive habits of breeding waterfowl, it is unlikely that anyone would witness kills of pre-fledged individuals. Most of the documented waterfowl mortality caused by Furadan 4F occurred when flocks of adult birds fed on treated crops, and the kills were primarily in alfalfa fields.

In the US where the bulk of the grazing bird kills have been reported, the application rate of carboran in alfalfa range from 140 to 1120 g ai/ha.

8.4.4.1.1 May 1972, Lassen County, Susanville, California

Field personnel observed 13 dead Canada geese, and captured six geese that exhibited signs of poisoning (but later recovered). The incident report does not include the application rate. Investigators found dead geese for 24 hours following application. Carbofuran residues in one alfalfa sample were 15 ppm 60 hours post-application. One sample from a goose's proventriculus (the first part of the stomach where food is mixed before reaching the gizzard) contained 15.5 ppm carbofuran (CDFG 1973).

8.4.4.1.2 March 1974, Riverside County, California

A farmer applied 580 g ai/ha carbofuran by ground. The alfalfa field was less than 300 metres from a reservoir and adjacent duck habitat used by a hunting club. The next day, observers found about 2 450 American wigeon (*Anas Americana*), one mallard, and two Canada geese dead. Carbofuran residues were present both in duck stomach contents (0.62 ppm) and collected alfalfa (3.6 ppm). In response to the incident, the County Agricultural Commissioner banned the uses of carbofuran in the area until the wigeon had departed. The California Department of Fish and Game agreed to furnish the Agricultural Commissioner information about the presence of grazing waterfowl that the Agricultural Commissioner could then consider before issuing permits to apply carbofuran. In addition, CDFG suggested to the US EPA that the Furadan 4F formulation be revised

to prohibit applications within one mile (1.6 km) of nesting or grazing waterfowl (a suggestion to which FMC agreed). However, in a press release issued by the CDFG, it was noted that the grower could not have prevented the kill because wigeon tend to feed at night undetected. Logically, this casts serious doubts on any pesticide applicator's ability to detect feeding waterfowl as required by the label so as to follow the one mile prohibition.

8.4.4.1.3 April 1975, Patterson Lake, Mount Hope, Kansas
A farmer applied carbofuran by ground at 1.1 kg ai/ha. Investigators found carcasses of 79 American coot, one cottontail rabbit, and one frog (*Rana sp.*) (US EPA 1979).

8.4.4.1.4 February 1976, Tishomingo National Wildlife Refuge, Oklahoma
A farmer applied carbofuran by ground at 560 g ai/ha. Birds landed in the field soon after the pesticide treatment. Investigators then found about 500 dead Canada geese (Jemison 1976).

8.4.4.1.5 March 1976, San Jacinto Reservoir, California
Investigators recovered 63 dead American wigeon. Laboratory analysis determined carbofuran residues, including 11.4 ppm in a pooled gastrointestinal tract sample from five of the birds. It was not possible to isolate the field that served as a source of the carbofuran, which also prevented investigators from recovering further details about this incident (CDFG 1976).

8.4.4.1.6 April/May 1976, Mount Hope, Kansas
An estimated 750 to 1 000 American wigeon were reported dead in this incident. Investigators found the ducks two days after the field was sprayed, but time of death is not known. Pooled stomach contents of three birds analysed five days after application contained 0.5 ppm carbofuran (US EPA 1979; Flickinger, King, Stout et al. 1980).

8.4.4.1.7 March 1977, Willows, California
Investigators found approximately 1 100 American wigeon dead in and near an alfalfa field treated by aircraft with 560 g ai/ha. The field was about four kilometres from the Sacramento National Wildlife Refuge. The crop stood at about five centimetres when sprayed. Carbofuran residues in the alfalfa were 42 ppm (time of collection unspecified), and pooled duck proventriculus samples contained 9.8 ppm carbofuran. Brain cholinesterase levels were depressed 54 to 77% in a sample of six dead birds (Bischoff 1977; O'Connell 1977; Hill and Fleming 1982).

This case set a precedent in United States law when a judge ruled that the defendants (i.e., the applicator, farm owner, dealer, and salesperson) were indictable under the Migratory Birds Treaty Act (referred to as the Migratory Birds Convention Act in Canada) for killing migratory birds with a pesticide, even though there was no intent to do so (Williams 1988).

American wigeon also died in another California kill the next September, but Coon (1983) did not provide details, including the number of birds recovered. Another poorly reported incident involved 18 to 19 geese (US EPA 1979).

8.4.4.1.8 April 1985, Stevens County, Oklahoma
A pesticide applicator treated an alfalfa field with Furadan 4F aerially at 560 g ai/ha. About 150 and 160 American wigeon and ten Canada geese were found dead after feeding on the treated alfalfa (Chada 1987).

8.4.4.1.9 August 1989, turnip, Westminster, British Columbia
Investigators found more than 40 dead or convulsing Canada geese in a turnip field. Rain on the previous day caused puddling in the field. The farmer had applied Furadan 4F the previous evening thereby contaminating the puddles directly. Three turnip seedling samples contained 32.1, 68.7 and 1.7 ppm carbofuran. Two goose gut samples sent for analysis contained 0.055 and 0.350 ppm carbofuran.

Analysis of soil samples (unreported levels) indicated that the farmer had applied carbofuran at the correct rate (British Columbia Ministry of Agriculture and Fisheries 1989; Whitehead 1989).

8.4.4.1.10 February 1995, alfalfa, Imperial County, California
Observers reported 61 dead American wigeon and one mallard in this incident (Fite, Randall, Young et al. 2006). They had been grazing on the alfalfa. Positive residue determinations were obtained on three birds.

8.4.4.1.11 June 1996, alfalfa, Modoc County, California
Fite, Randall, Young et al. (2006) report that six Canada geese were killed and 100 affected following aerial application of the insecticide. Two gut content samples were measured at 0.4 and 1.5 ppm.

8.4.4.1.12 June 1997, alfalfa, Loudoun County, Virginia
Six Canada geese found dead at a reservoir had grazed in a nearby treated field. Stomach contents (it is not clear whether from a single bird or a pooled sample) contained 8.6 ppm carbofuran (Fite, Randall, Young et al. 2006).

8.4.4.1.13 March 1999, alfalfa, San Bernardino County, California
Observers reported 40 dead American wigeon in this incident (Fite, Randall, Young et al. 2006). Gastrointestinal tract contents ranged from 1.5 to 5.2 ppm carbofuran. Skin sampled from the foot of birds ranged from < 0.05 to 4.1 ppm.

8.4.4.1.14 March 2000, alfalfa, Chaves County, New Mexico
Fite and colleagues (2006) report a very large kill of 1 200 snow geese (*Chen caerulescens*) in a field treated with 840 g ai/ha. They provide no further details.

Clearly, waterfowl species that graze on treated vegetation risk exposure even at the lower registered rates of application. Other grazing species may also be at risk, although galliformes (e.g., grouse or pheasant) may be less sensitive than waterfowl on the basis of the species tested to date. In an unpublished Pesticide Informational Report of the CDFG, E. Littrell calculated that alfalfa residue levels of 2 ppm could still be potentially lethal to American wigeon a species of duck very prone to grazing in fields. Indeed, many of the values for gut contents reported in the incidents described in Section 8.4.4.1 are below this level. Littrell based this assessment on food consumption habits of waterfowl in alfalfa and on the LC_{50} value of 79 ppm established in the 14 day old mallard. On that basis, he proposed a 'safe re-entry interval' of seven days for waterfowl in sprayed alfalfa fields. Residue levels in alfalfa associated with instances of mass mortality in California were never higher than 44 ppm. Here, we caution the reader that the use of the LC_{50} to assess avian risk has largely been discredited. See Mineau, Jobin and Baril (1994).

8.4.4.2 Incidents where birds were killed by eating seeds or insects that were contaminated with liquid carbofuran

Based on the species affected, it is clear that carbofuran applied in liquid form kills much more than grazing species. In the following incidents, we surmise that the birds were feeding on wild or crop seeds and/or insects contaminated by either a foliar or a ground spray of carbofuran. When the governments of the United States and Canada severely restricted the legal uses of granular formulations of carbofuran, farmers began applying the flowable formulation directly to soil in increasing numbers. Not surprisingly, the majority of the more recent kills have involved this type of use.

8.4.4.2.1 April 1986, tomatoes, Virginia
Field personnel found at least eight American goldfinches (*Carduelis tristis*) near a tomato field sprayed with carbofuran. The birds' gizzard contents contained 0.17 ppm carbofuran. The birds

were in poor body condition and had probably just returned from migration. They may also have been feeding on food contaminated by the insecticide. However, nearby cornfields were treated with granular carbofuran, which was another potential source of the insecticide (Roth 1986).

8.4.4.2.2 June 1986, grasshopper control, Moose Jaw, Saskatchewan

Field personnel found an estimated 45 gulls convulsing after feeding on grasshoppers in a field that had been treated with carbofuran a few hours earlier. Carbofuran residue levels in grasshoppers retrieved from the oesophagi of the birds ranged from 4.2 to 7.2 ppm (Leighton and Wobeser 1987; Leighton 1988).

Residue levels measured in the dead gulls in this incident were on the high end of the range of levels expected from a normal application to control grasshoppers. Irvine and colleagues (refer to Section 8.4.2.2) reported peak grasshopper levels ranging from 0.45 to 6.6 ppm after an aerial application with 132 g ai/ha. Two samples of grasshoppers collected after an experimental ground application contained a mean of 2.5 ppm, but a gullet (i.e., oesophageal) sample from a gull shot and collected from the plot contained 5.7 ppm carbofuran.

8.4.4.2.3 August to September 1985, Alberta

Two other incidents involving gulls and possibly linked to carbofuran use in Alberta are not very well documented. About 70 ring-billed gulls (Larus delawarensis) died in August 1985 after eating grasshoppers. Carbofuran was suspected because of its popularity for grasshopper control but investigators did not analyse the samples for residues. Another 11 ring-billed gulls died at a different Alberta location in September, and their gut contents contained 2.7 ppm carbofuran. September is unusually late for grasshopper spraying, and the circumstances surrounding the kill remain unclear (Somers, Khan and Hawley 1988). During 1985, there was extensive spraying for grasshoppers in the Canadian prairies.

8.4.4.2.4 May 1988, corn, Le Bayou Noir, Louisiana

A biologist from the Louisiana Department of Fisheries and Wildlife reported that approximately (the birds were badly scavenged making an exact count difficult) 200 cattle egrets (*Bubulcus ibis*) died in a field seeded three weeks previously (Mullins 1988). The farmer, when questioned, related that he had sprayed liquid carbofuran directly into the seed furrows. However, the Commissioner of Agriculture for Louisiana (Odom 1988) contested this version of the facts and suggested that the farmer had instead treated his corn seed directly with the insecticide. He surmised that the egrets had actually fed directly on badly incorporated seed. The record does not indicate who was proven right. Problems resulting from the use of carbofuran as a seed treatment were outlined in Chapter 7.

8.4.4.2.5 April 1991, corn, King George and Isle of Wight Counties, Virginia

Fite, Randall, Young et al. (2006) reported that observers collected 51 carcasses from 22 different species near a corn field sprayed with carbofuran. This incident stands out for the sheer diversity of species killed by the pesticide. Given the timing and prevailing use pattern, this would have been a soil application, probably associated with seeding. Fite and colleagues report that brain cholinesterase levels and residues in the gastrointestinal tracts confirmed the diagnosis.

In a similar incident, also confirmed by residue identification and cholinesterase assays, observers reported another 51 birds and one small mammal carcass from more than seven different species.

8.4.4.2.6 April 1992, alfalfa, Caroline County, Virginia

Observers found two common grackles and four mourning doves by a watering hole in proximity to a treated field (Fite, Randall, Young et al. 2006). A combined sample of the grackle’s gizzards contained 15 ppm carbofuran but no residues were detected in the only two doves tested. A water

sample revealed 231 ppm carbofuran, so exposure from drinking water could have been a contributory factor.

8.4.4.2.7 March 1993, corn, San Joaquin County, California
An aerial application made to an alfalfa field killed 15 house finches, one house sparrow and a 'gopher' (the generic term used for a species of small mammal most likely to be a ground squirrel). Laboratory analysis revealed 0.49 ppm carbofuran in the gizzard contents of one finch and 1.8 ppm in the stomach content of the small mammal (Fite, Randall, Young et al. 2006). The latter probably grazed on the treated alfalfa.

8.4.4.2.8 May 1993, corn, Kent and New Castle Counties, Delaware
Fite and colleagues (2006) describe these applications as 'subsurface injections' of carbofuran. Nevertheless, in one application observers reported two dead tree swallows, a common grackle, a red-winged blackbird, a starling, a rock dove and a rat (species unreported). Gastrointestinal tract samples of the starling and rock dove contained 9.2 and 30.4 ppm of carbofuran, the other samples were negative. Following another application, observers reported two dead common grackles and a mallard. One grackle sample contained 15.3 ppm carbofuran while the other grackle and mallard were negative for residues.

8.4.4.2.9 August 1995, squash, Prince George County, Maryland
An application of 1120 g a.i/ha in-furrow at seeding came to light after observers reported a dead cardinal (*Cardinalis cardinalis*) as well as 11 Canada geese and two bald eagles killed on site (Fite, Randall, Young et al. 2006). Remains of small birds and seeds were found in the eagles suggesting that other birds had died in the incident; the eagle's gastrointestinal tract contents contained 2.35 and 3.1 ppm carbofuran.

8.4.4.2.10 May 1998, corn, Northampton County, Pennsylvania
Observers found a group of 13 birds (tentatively identified as grackles) near a pond about 25 metres from a treated cornfield (Fite, Randall, Young et al. 2006). Internal organ samples were positive for carbofuran. Investigators postulated that the higher wind speeds (circa 48 km/hour) promoted drift in the direction of the pond.

8.4.4.2.11 March 2006, alfalfa, Perry, Oklahoma
FMC reported an incident where approximately 100 blackbirds (this most likely refers to the red-winged blackbird) and two red-tailed hawks were found dead at the edge of an alfalfa field treated with Furadan 4F (US EPA 2009). Most mortality cases in alfalfa are the result of birds grazing vegetation directly (refer to Section 8.4.4.1). However, blackbirds do not graze. Based on the results of their internal investigation, FMC concluded that mortalities occurred in a discrete area where the custom applicator had cleared his spray lines prior to making the application to the field. FMC asserted that this practice led to an unusually high concentration of carbofuran. However, a soil sample analysis detected only 42 ppm carbofuran, a concentration well in the range of alfalfa samples following similar applications. It is unclear from the report how the birds had been exposed although we can surmise that the hawks died from secondary poisoning.

8.4.4.2.12 June 2006, sunflowers, Hugo, Colorado
In one dramatic incident, investigators found more than 2 200 birds poisoned by carbofuran in Hugo, Colorado (US EPA 2006, Archuleta 2008). The deaths occurred following a broadcast application of flowable carbofuran at 560 g ai/ha to a 95 acre no-till field before sunflowers were planted. Investigators from the US Fish and Wildlife Service collected 40 birds the first day and additional birds on following days. Most of the carcasses collected were mourning doves

(1 633 birds recovered) and horned larks (597 birds recovered). Investigators also identified 12 sparrows (species unspecified), five western meadowlarks (*Sturnella neglecta*), five common grackles, five red-winged blackbirds, one American robin, and one American kestrel (*Falco sparverius*). They also found 150 partially scavenged carcasses that could not be identified as well as dead kangaroo rats (Genus *Dipodomys*).

The farmer had planted the field to wheat the year before (2005). Previously, he had planted red millet (a component of commercial bird seed) in the field and had produced a good harvest. A hail storm severely damaged the wheat crop in July 2005 and may have resulted in a substantial amount of wheat grain being present on the soil surface. The farmer then planted sunflowers in the spring of 2006 but cutworm and wireworm damage destroyed about two thirds of the field. On 13 June 2006 the farmer did a 'burndown' broadcast treatment of 2,4-D and glyphosate to rid the field of sunflowers and weeds. He also added flowable carbofuran to the tank mix application.

The investigators from the US FWS observed grains of both wheat and red millet in the field at the time of the bird kill. It is likely that the presence and availability of this waste grain resulted in the kill being so large. Although the courts found the farmer guilty of some minor violations, the use itself was deemed a legal one. The investigators concluded that most of the birds had likely died after consuming the surface seed contaminated with the spray.

8.4.4.3 Incidents from carbofuran used in chemigation

Chemigation is the introduction of a pesticide into irrigation water. This can prove extremely hazardous to wildlife, especially in arid areas, where wildlife is drawn to any source of water.

In 1990, bird losses were reported in coastal wine growing counties in California. By early 1992, investigators had documented almost 2 000 bird deaths from exposure to carbofuran used on grapes (CDFG 1990b; CDFG 1990e-j; CDFG 1990l; CDFG 1990m; CDFG 1991a-w; CDFG 1992a; CDFG 1992b; CDFG 1992d). These losses were from applications of flowable carbofuran (Furadan 4F) through drip irrigation systems during the day. A drought in California during this time likely exacerbated the situation by drawing large numbers of birds to available water in vineyards. Investigators also documented secondary poisoning of predatory birds preying on songbirds.

In order to prevent further bird loss, State authorities cancelled the use of Furadan 4F in Napa, Sonoma, and Mendocino counties and changed label directions in other counties to prohibit use of carbofuran during daylight hours. In Monterey County, government regulators implemented an intensive post-application field monitoring programme in the autumn of 1992. Carcasses of more than 400 animals (birds, mammals, reptiles, and amphibians) were recovered from vineyards in the monitoring programme and carbofuran was detected in each carcass that was analyzed (CDFG 1992e-h; CDFG 1993a-f; CDFG 1993h-p). Most of the carcasses recovered were diurnal passerines, indicating that prohibiting diurnal applications did not offer sufficient protection to these species. Analysis revealed that grapes, weed seeds, and leaf litter on the soil surface surrounding the drip emitters had been coated with carbofuran as a result of splashing from the drip puddles. It is interesting to note that no other losses were reported in the county, indicating that, without a directed post-application monitoring programme, important wildlife losses would not have been detected or reported (Finlayson, McMillin and Hosea, unpublished report).

In response to the monitoring results, alternative methods of application including subsurface drip emitters and tubing connecting above ground emitters directly to the soil surface were developed and tested. The new methods revealed up to a 90% reduction in detectable wildlife losses. Indeed, only one wildlife loss (in grapes) has been reported state-wide since 1993 (CDFG 1995b). However, Fite, Randall, Young et al. (2006) pointed out that limited information is available on the effectiveness of these mitigation measures. Carbofuran use declined substantially after 1994, as did all monitoring efforts to uncover any further problems.

8.5 Evidence for secondary poisoning impacts with any formulation type

Balcomb (1983) published the first widely available report of a predator or scavenger dying after eating a bird or mammal that had been poisoned by granular carbofuran. Until then, scientists generally had not considered this hazard despite a few earlier indications that it was a problem. For example, investigators had documented the deaths of an unidentified hawk in the British Columbia waterfowl kills (refer back to Section 8.2.2.2.3). Balcomb showed that the quantity of carbofuran in the gastrointestinal tracts of songbirds killed by Furadan 10G (this was after in-furrow application in maize) could be sufficient to kill a larger-bodied predator or scavenger. Predators or scavengers that eat their prey whole or eat the viscera of their prey are at the greatest risk of consuming unassimilated residues.

Mineau and colleagues (1999) inventoried documented kills of birds of prey from carbofuran that occurred in the United States, Canada and the United Kingdom during 1985 to 1995. For the purpose of their review, they defined secondary poisoning as the passing of residues from vertebrate to vertebrate. This is a broader definition of secondary poisoning than that which was established from our experience with persistent organochlorine pesticides. In that case, residues have resisted metabolism and have been sequestered in fat deposits. In the case of organophosphorous and carbamate insecticides, much of the potential for secondary poisoning lies in the ingestion of unassimilated residues present in the gut of the prey. Despite restrictions, carbofuran was more frequently implicated in secondary poisoning cases than any other cholinesterase-inhibiting insecticide. The likely route of exposure was by scavengers eating gastrointestinal tract contents of songbirds or waterfowl.

Booth and colleagues (FMC 1983, described in Section 8.2.1.2) reported mortality of a northern harrier and short-eared owl in their study of the granular formulation in maize. Littrell (1988) reported a northern harrier and red-tailed hawk in association with the use of the 5G product in rice. In one incident that involved the cultivation of winter wheat, it appeared that granules contaminating an existing fox (*Vulpes* sp.) carcass (the planting equipment likely ran over the carcass) subsequently killed both a bald eagle and a red-tailed hawk.

California had a relatively steady occurance of secondary poisoning incidents from carbofuran in birds of prey from the late 1980s to the early 1990s. Rice and grapes were the crops associated with most of the incidents. Red-tailed hawks were the most commonly impacted species, accounting for 67% (14/21) of incidents. Most of the hawk crops analysed contained parts of passerine birds, or more infrequently, waterfowl or rodents, confirming secondary poisoning as the route of exposure (CDFG 1985f; CDFG 1986f; CDFG 1990a; CDFG 1990e; CDFG 1990k; CDFG 1991c; CDFG 1991d, CDFG 1992a; CDFG 1992b; CDFG 1992c; CDFG 1993h).

The largest incidence of secondary poisoning occurred between 1989 and 1990 when investigators found about 15 or 16 bald eagles and four red-tailed hawks moribund or dead in the immediate Richmond–Ladner area in the lower mainland of British Columbia (Mineau 1990; Elliott and Wilson 1993; Elliott, Langelier, Mineau et al. 1996). There have been several documented waterfowl kills resulting from carbofuran use on root crops in this area (refer back to Section 8.2.2.2). Moribund birds were typically lethargic, unable to stand, exhibited balance problems or lack of coordination, had a fixed or 'vacant' stare and constricted pupils, and a body temperature below normal (refer back to Chapter 2). These signs are all consistent with acute poisoning with a cholinesterase-inhibiting agent, and carbofuran was the principal insecticide in use in the root crops at the time. The birds had full crops, a noticeable 'chemical' odour on the breath and in the crop contents, and an oily, reddish-brown exudate in the mouth and crop. Balcomb (1983) reported that a red-shouldered hawk (*Buteo lineatus*) secondarily poisoned by Furadan 10G salivated a 'brown fluid'. All the hawks and eagles were in good flesh. Also, some cases were associated with the presence of waterfowl displaying signs of toxicity.

The arrival of dead or moribund birds appeared to follow periods of rain, conditions documented as being conducive to waterfowl mortality in fields treated with granular carbofuran. Laboratory personnel either forcibly removed crop contents by hand or surgically emptied the crop in most of the birds, who recovered very rapidly after this procedure. Again, this is consistent with poisoning with a carbamate insecticide. In all cases, hawk and eagle crops contained duck or gull body parts.

Only nine birds were available for a proper postmortem and, for logistical reasons, it was only possible to chemically analyse crop contents of two bald eagles and two red-tailed hawks (Elliott, Langelier, Mineau et al. 1996). One bird contained no detectable residues, one bird had residues of fensulfothion, and two had carbofuran. One bald eagle had levels of 200 ppm; a red-tailed hawk had 2 ppm. Ironically, the hawk with 2 ppm had significantly depressed brain cholinesterase; the eagle with 200 ppm did not. In a well-documented bald eagle kill related to the use of granular carbofuran in maize, one bird with a 58.6% inhibition of brain cholinesterase (diagnostic of ingesting a potentially lethal dose) had crop content residues of 0.64 ppm carbofuran. This bird had scavenged remains of rock doves (*Columba livia*) and blackbirds (Hill and Swineford 1985; Thomas 1985; Patterson 1986). Chapter 2 provides a discussion of the frequent lack of correspondence between cholinesterase levels and carbofuran exposure.

Finally, the presence of duck and gull feathers in all the birds and the apparent association of the kills with periods of rain suggest that the birds were able to locate kills of waterfowl resulting from insecticide use including carbofuran.

Furadan is one of the few modern pesticides toxic enough to cause secondary toxicity in birds that scavenge primary casualties, killed from the use of the liquid formulation. In one of their own studies, the manufacturer (FMC 1989a) reported affected (paralysed) northern harriers both in their Texas/New Mexico study in maize and in the alfalfa study in Kansas. In the latter case, the bird was still clutching its prey, an eastern cottontail found to contain 0.1 ppm carbofuran residues. In a 1995 incident (see 8.4.4.2.9 above) use of the liquid formulation in-furrow at seeding resulted in kills of waterfowl, songbirds and of bald eagles that scavenged the songbird carcasses. In a 2006 incident documented previously in Section 8.4.4.2.11, FMC personnel reported two red-tailed hawks that died along with 100 blackbirds in an alfalfa field.

8.6 Impacts resulting from abuse cases regardless of formulation

Over the years, those individuals intent on poisoning unwanted wildlife have recognised carbofuran as an ideal toxicant. Its extreme toxicity to both birds and mammals and variation in formulation type makes it a popular product for illegal usage. The variety of cases in terms of the bait type and method of presentation to the target wildlife is only limited by the imagination of the perpetrator. The subject of carbofuran abuse/misuse is dealt with extensively throughout the rest of this book and only major trends and tendencies will be reviewed here.

Cases of pesticide abuse are more likely to be reported than cases resulting from the legal regulated use of pesticides. Perpetrators of abusive poisoning often use highly concentrated baits which render the victims unable to venture far from the site of poisoning (the so-called 'circle of poison' with the bait at the centre). Birds able to fly away from a site of exposure are less likely to be recovered and analysed for residues; authorities typically investigate cases of abuse more vigorously, given the legal requirements and statutes in North America. Abuse cases are considered less 'sensitive' in that they do not reflect on that jurisdiction's agricultural operations and they are more likely to be publicised. The local citizenry may be reluctant to report problems stemming from normal labelled use of pesticides if they believe the pesticide implicated to be essential to their livelihood or that of someone in their community.

In a review of pesticide poisoning of birds of prey between 1985 and 1995, Mineau and colleagues (1999) estimated that, where this could be determined, 69 and 67% of the carbofuran incidents

involving birds of prey in the United States and Canada, respectively, were the result of abuse. For all organophosphorous and carbamate insecticides pooled, the proportion of abuse cases was 54% for the United States and 35% for Canada – showing that carbofuran is often a preferred pesticide for abusive poisoning. Indeed, carbofuran accounted for 75% of all known organophosphorous and carbamate abuse cases and 50% of Canadian cases. Some species have borne the brunt of abusive poisonings. For example, the finding of poisoned golden eagles (*Aquila chrysaetos*) is almost always associated with abuse cases, typically stemming from attempts to poison them directly or efforts to poison large predators such as coyotes (*Canis latrans*). Allen, Veatch, Stroud et al. (1996) described how Furadan 4F was applied to sheep carcasses and persisted at levels capable of killing eagles and hawks for at least two months. Wobeser and colleagues (2004) summarised cases in Western Canada occurring between 1993 and 2002. A total of 54 separate incidents resulted from the use of cholinesterase inhibiting insecticides with either bald or golden eagle as the species involved in the incident. The identity of the toxicant was only possible for eight of these incidents and all eight were carbofuran cases (several incidents were diagnosed from cholinesterase assays only and samples were not sent for analysis).

8.7 Conclusions

Insecticides such as carbofuran came into use in the late 1960s with the expectation of avoiding the environmental problems associated with persistent organochlorines. The relatively rapid breakdown of carbofuran under most conditions (its long persistence in acid soils had not been discovered at the time) allowed it to be rapidly registered for a wide variety of uses. However, soon after its introduction, wildlife managers and regulators began to raise concerns about its high toxicity and ability to kill birds under many different circumstances.

The copious data reviewed in this chapter provide compelling documentation of the lethality of carbofuran to birds when used under operational conditions. Kills have been documented with every formulation, and under a wide variety of use patterns and crops. Attempts to reduce or mitigate impacts through draconian controls and extensive changes to standard agricultural practices have had mixed success and, in some cases, have failed completely (for example, refer back to Section 8.2.1.7 for attempt in the State of Virginia). Given that few State or Provincial jurisdictions in the United States or Canada have adequate resources to detect, investigate, and document fish and wildlife kills, the extent of data summarised in this chapter is even more remarkable. Considerable field data unequivocally affirm that there are no known circumstances under which carbofuran can be used without killing birds, perhaps not following every application but with a very high probability. Carbofuran gained such notoriety as a bird killer in North America that even professional ornithological associations took notice and petitioned government for a cancellation (e.g., American Ornithologist's Union 1990).

Unfortunately, as reviewed by Mineau (2004), regulatory changes associated with bird protection have tended to move at a glacial pace in North America. More than 40 years after the pesticide's introduction, the last remaining uses of carbofuran have finally been cancelled in both Canada and the US although legal challenges from the manufacturer are probably not over (as discussed in the Conclusion). It is sobering to ponder the difficulties in store for developing countries that would like to similarly protect their environment and their birdlife in particular.

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9 Conclusions, recommendations and the way forward

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9.1 Wildlife mortality stemming from intentional misuse and legal/labelled use of carbofuran

The overall objectives of this book were to:

- provide an up-to-date, accurate and balanced account of the global impact of carbofuran use on wildlife (to complete this picture, the Appendix at the end of this chapter summarises its use in Israel, Australia and New Zealand),
- report on the responses and strategies adopted within the conservation community, and,
- share the relevant analytical and forensic methodologies used to detect carbofuran.

Chapter 1 provided an overview of the chemistry, environmental fate, manufacture, and analysis of carbofuran. It also discussed compounds which have a similar chemical structure, mode of action, and pattern of environmental degradation (e.g., carbosulfan). Chapter 2 gave toxicity values for carbofuran (in birds and mammals), listed potential exposure routes, described the effects of intoxication and the typical signs/symptoms, discussed biochemical diagnosis of carbofuran poisoning, offered advice on gathering evidence in the field, and outlined rehabilitation approaches. From Chapter 3 onward, incidents of wildlife mortality, whether arising from deliberate misuse (e.g., in baits), accidental misuse or legal/labelled use of carbofuran (i.e., during agricultural applications) were reported.

The two central themes that emerge from the book are that:

1. The key driving force behind intentional poisoning is human-wildlife conflict, and poisonings will continue unabated until the core factors that result in such conflicts are addressed.
2. Legal/labelled uses of carbofuran pose a threat to wildlife that cannot be mitigated because the compound is inherently unsafe.

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Human-wildlife conflict primarily stems from an incompatibility between land management practices and wildlife behaviours, all within a decreasing land and resource base. In addition to the threats that wildlife pose (both real and imagined) to human sustenance (see especially Chapter 3 and 4), 'leisure-based conflicts' were also highlighted (see Chapters 5 and 6). For example, introduced game species (e.g., bears, boars and wolves, in Croatia) may damage crops or predate livestock, birds of prey may reduce game bird numbers on hunting estates (in the UK), or even interfere with egg collecting activities (in the Netherlands). In some instances (e.g., in Spain) the act of poisoning and baiting can extend beyond predator control and constitute a sort of 'sport' in itself. Also, on numerous occasions, cultural taboos and misperceptions (some based on religious teachings, as discussed in Section 3.3) have led to persecution and wildlife poisoning.

Even if such misperceptions were addressed, and incidents of persecution were reduced accordingly, the underlying issue still remains: carbofuran is unacceptably and inherently toxic to nontarget wildlife. From its release onto the market in the late 1960s up to the publication of this book, legal and 'careless' use of carbofuran has been implicated in the deaths of many tens of thousands of birds worldwide, and is suspected to have caused the deaths of millions of others over the 40 to 50-year period. The risks posed to mammals, aquatic organisms and beneficial insects have scarcely been investigated.

Of necessity, manufacturers have long sought to cast the product in a positive light. For example, in its 'Environmental Stewardship Guidelines' (see http://www.furadanfacts.com/Portals/furadanfacts/Content/Docs/FuradanEnvironmentalStewardshipGuidelines.pdf), FMC (the major global manufacturer of carbofuran) offers a number of 'safe' application tips, and states that:

> Frequently, farmland borders wildlife habitats which provide shelter and food for a variety of birds and other wildlife. Special attention is required when applying pesticides to maintain a balance between agricultural productivity and natural resources. Proper pesticide use allows farmers to continue farming efficiently and to continue using the products they need to maintain consistently favorable yields. Understanding and abiding by the product label is the most important step to product stewardship.

To be accurate, such a statement must rely on several assumptions, namely that a) wildlife do not actually enter farmland or use it as a 'habitat', and b) nontarget damage to natural resources is an acceptable bi-product of modern agricultural practice. An exhaustive list of case study from the United States and Canada (see Chapter 8) documents how wildlife (primarily avian) mortality inevitably follows the labelled/legal use of carbofuran, which contrasts rather sharply with FMC's stance.

Another fundamental flaw in the statement is that the onus remains on the grower/farmer to comply with the recommended wildlife protection measures and 'safely' apply a product that is fundamentally unsafe to nontarget wildlife. On its website, under the heading of 'Proper Use', FMC states the following: 'FMC believes the proper use of Furadan does not create a risk to human health, wildlife, or the environment, and we will continue to promote its responsible use' (http://www.furadanfacts.com/).

Taken together, the implication of these stewardship and product use statements is that wildlife mortality following an application of carbofuran is likely to have occurred because the farmer/grower did not 'understand and abide by' the product label. But following the label instructions may also produce unexpected results. In Chapter 8, Mineau and colleagues noted a wide range of recovery rates for carbofuran in treated fields (from 66 to 210%), even when the solutions being applied were mixed by trained personnel of the manufacturer (in this case FMC). For all these reasons, placing the responsibility for wildlife mortality solely at the door of the farmer/grower (who also represents the corporation's client base), even in the absence of negligence or wrongdoing, is disingenuous.

Although manufacturers could be commended for efforts to make certain products less palatable to wildlife, the reality is that such efforts have not worked. During studies such as the one described in Chapter 7 (i.e., in Brazil, which investigated the effectiveness of using repellent substances as a seed

treatment), post-application wildlife mortality was not appreciably reduced (likely because the toxicity of the product masked any effectiveness of the repellent substance). This study had as its basis the very real fact that so few mitigative methods have thus far been successful, as noted in specific cases.

It is also quite noteworthy that several of the most damning studies reported in Chapter 8 were actually conducted by the manufacturer (in this case FMC), under agronomic and operational conditions that could be described as 'idealised', in the sense of seldom being encountered in standard agricultural practice. While such mortality is largely deemed unacceptable in the 'developed' world (as demonstrated by the fact that many countries have now banned carbofuran use), developed world manufacturers continue to export this extremely toxic compound to developing nations. And now manufacturers in developing nations are also producing and exporting it.

9.2 Overall recommendations and the way forward

Section 9.1 identified and discussed the two quite distinct but interrelated issues that have emerged from this book, which are that: carbofuran is fundamentally unsafe to wildlife, and that most intentional poisonings using carbofuran stem from some form of human-wildlife conflict. Regulatory and policy efforts aimed at restricting access to, and use of, carbofuran are ongoing (refer to Section 9.2.6), and have spanned the better part of 40 years. However, such efforts serve to restrict the use of this particular compound only, and do not address the issue of wildlife poisoning itself. The following general recommendations are therefore offered, in an attempt to significantly reduce incidents of carbofuran-related wildlife mortality and to generate further awareness regarding the human health risks posed while attempts to remove it from most or all agronomic uses shown to be inherently unsafe are underway:

1. Address and mitigate the root causes of human-wildlife conflict.
2. Increase grassroots educational initiatives.
3. Enhance analytical capacity and increase sampling, testing and monitoring efforts.
4. Conduct studies in important but currently under-represented fields.
5. Coordinate international conservation and monitoring efforts.
6. Address outstanding policy and accountability issues.

9.2.1 Address and mitigate the root causes of human-wildlife conflict

Human-wildlife conflict is a key driver behind many instances of wilful wildlife poisoning with carbofuran. This conflict arises as a result of competition for increasingly limited habitat and environmental resources. Conflict that is 'leisure-based' (i.e., stemming from recreational rather than subsistence-based hunting activities, for example) is also of ongoing concern. Until the socioeconomic factors that pit people against wildlife, especially in developing countries, are fully addressed, such forms of conflict, and the ensuing incidences of poisoning, will persist. While many of the case studies presented (e.g., in Chapters 3 and 6) indicate that carbofuran is a 'poison of choice' globally and that the product offers many advantages as a poison, Chapters 4 (India) and 5 (Europe) suggest that it is one among a larger list. Hence, if the availability of carbofuran is restricted, other products will almost certainly be used instead. This does not in any way mean, however, that it is futile to deal with the use of carbofuran as a poison, or that its manufacturers should be absolved of their responsibilities.

9.2.2 Increase grassroots educational initiatives

Educational programmes delivered at a grassroots level can effectively decrease some of the intolerance and animosity that is directed towards wildlife, particularly if they are presented by other local people. Such programmes can also provide an opportunity for people to express their frustrations and concerns (i.e., what drives an individual or community to persecute a particular species), and to feel they are being heard on these matters. Measures that sustainably and pragmatically address and integrate the needs of people and wildlife must be developed and implemented (see especially Chapter 4). Overall, there is a need for dialogue regarding the importance of wildlife and of maintaining biodiversity. In Chapter 5, for example, a number of contributors expressed frustration at being faced with the fact that poisoned wildlife are not even deemed 'important enough' to justify toxicological and forensic analyses. Clearly ascertaining and highlighting the economic benefits of wildlife (and the fact that communities and countries are impoverished by the loss of biodiversity), may in turn help break down taboos and ingrain a sense of the benefits of wildlife.

It is also essential that farmers/growers receive proper training on the use of pesticides and the measures they should take to protect wildlife. People must be informed of the consequences of improper use and handling of pesticides to human health and to wildlife/ecosystem health. 'Pesticide hotlines' and 'poisoning response programmes' are needed where such information structures are currently lacking. There must also be frank and open communication between users, suppliers and agronomic advisers. The overriding perception (particularly in the developing world), and one that has been advanced by manufacturers, is that carbofuran is a product ' . . . they need to maintain consistently favorable yields' (as per the FMC statement above). In other words, manufacturers are making the highly persuasive argument that the use of carbofuran is integral to crop success and, by extension, to global food security. However, there are usually much safer pesticides available at comparable costs. Also, pesticides are by no means the sole method that can be used to manage pest species in crops. Users/growers do have a range of agricultural options available to them (e.g., integrated pest management, organic practice and benefits, the pre-testing of soil for nematodes, that would allow them to minimise carbofuran use wherever possible), which they should be fully aware of so that they can make informed choices regarding whether or not to use carbofuran. Such measures would, in themselves, save users/growers a considerable amount of money, and potentially reduce wildlife mortality. It is also noteworthy in this context that the US EPA concluded that the risks carbofuran posed to people and the environment far outweighed the benefits of continued use (http://www.epa.gov/opp00001/reregistration/carbofuran/carbofuran_noic.htm).

Finally, the ability of users to recognise and correctly identify products and trade names is absolutely crucial to the success of initial surveying and on-the-ground monitoring efforts. For example, in Kenya, people sometimes collectively call the pesticides they use as poisons 'Furadan', which itself is often referred to as 'dawa', i.e., poison. In the absence of analytical infrastructure (discussed in Section 9.2.4), the accuracy of anecdotal information becomes particularly important. And, when several forms of carbofuran are available, correct identification of the trade name(s) is essential in tracing the source of the product and identifying its manufacturer.

9.2.3 Enhance analytical capacity and increase sampling, testing and monitoring efforts

A recurring theme throughout the book is that only a fraction of poisoned wildlife are actually detected and reported. In many (though not all) cases, sampling is conducted in an opportunistic rather than routine, concerted manner. This is often due to logistical constraints (e.g., the remoteness of field locations). Intuitively, by implementing systematic monitoring networks, a better overall

picture of real trends and patterns will emerge. Pragmatically, the level of analytical capacity available worldwide differs markedly, as described in this book. Excellent analytical infrastructure and innovative detection/preventive measures are often in place in certain areas (e.g., the UK, some parts of Europe and the United States/Canada). Unfortunately, in other areas (e.g., Kenya), the evidence that is being collected is largely anecdotal, and, until monitoring systems are implemented to collect evidence that is forensically robust, it will be difficult to mount strong legal cases. In the fairly extreme example of Kenya, it must further be noted that, while equipment is available and qualified staff are willing and able to use it, there is a dearth of accredited, 'independent' testing facilities (i.e., not linked to the government or the agricultural industry in some way). Unfortunately, ethical issues have arisen, which has led to mistrust regarding the accuracy of results and, in some cases, outright refusals by laboratories to test samples following intense lobby and pressure by agricultural and government interests.

The international community has an important role to play in levelling the analytical playing field and smoothing out some of the ethical concerns. For example, a number of charitable/nonprofit organisations now donate new or refurbished analytical instruments to developing countries and offer long-term technical expertise. Collaborations between analysts, researchers and conservationists can also be pursued. Projects can be initiated, common funding secured, and expertise exchanged (particularly regarding the latest developments in analytical techniques). International 'watchdog' groups could be appointed to conduct independent analysis or offer independent accreditation to local entities. While certain fundamental procedures must be followed to maintain the chemical and forensic integrity of samples, protocols must also take into account real logistical constraints (e.g., of distance, extreme environmental conditions, intermittent power supply and existing analytical capacity). Internationally-recognised and approved protocols, outlining collection standards, storage standards, and sample testing should be developed and adapted to fit the needs and realities of each country. Protocols that involve simple/user-friendly and cost-effective sample collection and analyses are most likely to be adopted.

9.2.4 Conduct studies in critical but currently under-represented fields

The contributions offered in this book reflect the extent to which the issue of carbofuran use and wildlife poisoning, in its many facets, has been studied. A difficulty has been that, up to now, such studies have not been consolidated to enable key gaps in knowledge. In this regard, several important but under-represented topics have emerged in this book, particularly concerning risk assessment in humans.

Chapter 3 highlighted a practice where carbofuran is used in a way in which it was never intended, i.e., to poison birds and fish that are destined for human consumption. The health risks posed to individuals (e.g., hunters/poachers and consumers) who knowingly and willingly eat poisoned meat must be addressed. This will require an assessment of residues in poisoned meat that compares the impact, if any, of regional and traditional means of food preparation (e.g., hanging and roasting wild birds prior to consumption). In terms of agricultural use, many farmers worldwide do not wear protective clothing, either because they cannot afford to purchase it, they are unaware of its necessity or, in tropical climates, because they find it too uncomfortable. Further research is also required to assess exposure levels sustained during such occupational use.

Likewise, there do not seem to have been any studies which compare or at least consider crop application volumes to end residues in foodstuffs. As mentioned in Section 9.2.2, there is an entrenched mindset within the farming industry that pesticide application is indispensable for crop integrity and food security. A number of alternative agricultural initiatives have been trialled to lessen our dependency on highly toxic and broad spectrum pesticides, including carbofuran

(e.g., see Chapter 4). Further research into region-specific integrated pest management is also needed. Finally, despite the fact that carbofuran is known to persist in acidic soils/under acidic conditions, further discussed in Chapters 3 and 8, the authors of these sections were unable to find any detailed studies that examined whether or not this has resulted in increased levels of carbofuran residues in agricultural produce, although this seems warranted.

Carbofuran is by no means the only toxic compound used to poison wildlife, and others (e.g., the carbamate carbosulfan) can degrade to yield carbofuran and/or the same metabolites (as outlined in Chapter 1). Both compounds are highly toxic to wildlife, so from an ecotoxicological perspective, their dual presence presents to some degree a 'six of one and half a dozen of the other' scenario (a factor discussed in Chapter 7). However, from an evidentiary perspective, without a full and detailed investigation which identifies all possible compounds of use and concern, carbofuran may on occasion be implicated incorrectly in a wildlife poisoning incident, a finding that its manufacturers can then use to undermine the credibility of the process. Focusing on any single compound or group of compounds may well be detrimental if others are later implicated, especially in terms of fully resolving this ongoing issue. As a gesture of goodwill, manufacturers could examine the feasibility of adding a diagnostic marker to their products (or explore the possibility of making the colour and shape of their product visually distinctive), so that they could be readily identified and distinguished from (or as) carbofuran during field assessment and laboratory analysis. Similarly, camouflaging, as described in Chapter 7, was shown to be a promising way to conceal poisoned seeds, decrease mortality and, hence, reduce damage caused by birds in wheat, corn and rice plantations.

9.2.5 Coordinate international monitoring and conservation efforts

Of the wildlife that has succumbed to carbofuran poisoning, birds have been hardest hit, not only because of their inability to detoxify the compound before it kills them (as discussed in Chapters 1 and 2), but also because they are the most mobile. The scale of migratory bird poisoning has been substantial, and likely carries global population level repercussions for certain species (a possibility further explored in Chapter 3). Conservation efforts conducted worldwide to protect migratory birds are now being undermined by global discrepancies in carbofuran regulations. For example, birds rehabilitated and released in Israel (where carbofuran is not registered for use), may be decimated when they arrive in Africa or Asia. It is also worth noting that migratory birds are famished at the end of their journey and gorge themselves on the prey they can find (as described in Section 3.3), which may predispose them to consuming poisoned/intoxicated individuals. International treaties and regulations (e.g., the Migratory Bird Conventions Act, http://laws-lois.justice.gc.ca/eng/acts/M-7.01/FullText.html) can and have been invoked to protect migratory birds from inconsistent pesticide regulations throughout their ranges. International entities can work in partnership to seek common funding and pool resources and information to effectively protect species throughout their migratory ranges.

9.2.6 Address outstanding policy and accountability issues

Although this is by no means a simple scenario, several fundamental logistical constraints and 'villains' can be clearly identified. As outlined in Section 9.2.3, a lack of capacity and of financial resources severely limits the quality of the information and evidence that can be gathered. However, it can be a struggle to recover and analyse samples even in 'developed' nations. While people on the ground certainly do not lack dedication or drive, both the political will and the societal interest to propel it must follow suit. Conservationists must find ways to affect change through the existing

policies and, when necessary, to acquire the clout that is required to further strengthen these policies. However, the chemical and farming industries will always resist attempts at regulation, and governments are often all too slow to deal with this issue.

Governments are responsible for protecting their own people and safeguarding the environmental riches of their countries, although this may not always be evident based on their actions. They must work in partnership with chemical corporations, conservationists, and the research community to implement the recommendations detailed in this chapter. They must also be at the forefront in financing such interventions. The government of Argentina provided a commendable example of leadership when it canceled the use of the organophosphate monocrotophos following the deaths of an estimated 5 000 plus Swainson's hawks (*Buteo swainsoni*) in a single season of grasshopper control. Manufacturers must also be held accountable for the repercussions that their products have on human, wildlife and ecosystem health.

In the absence of tangible government action, private citizens can also sometimes intervene. In July 2009, for example, David Brook, a practicing attorney in the United States saw the '60 Minutes' segment entitled 'Poison Takes Toll On Africa's Lions',(http://www.cbsnews.com/stories/2009/03/26/60minutes/main4894945.shtml, and see Chapter 3) and was deeply affected by both the content and the implications of the piece. After consulting the rules of the US Securities and Exchange Committee (SEC, http://www.sec.gov/), the governmental body that oversees the operation of corporations and is mandated to ensure they comply with existing regulations and laws, he purchased stock in FMC Corporation (i.e., 'FMC') the next day. According to SEC Rule 14A-8, corporations are obligated to entertain proposals from owners, i.e., 'shareholders', who must hold a qualifying dollar amount of stock for one year before a shareholder proposal can be brought forward. In November 2010, Mr Brook prepared and submitted a shareholder proposal to FMC. In essence, the proposal stated that FMC:

1. Did not have a solid grasp on the use of its product, Furadan, to poison wildlife, especially lions, in Kenya.
2. Needed to establish a credible stewardship programme to address (1).
3. Had an obligation to determine whether or not FMC products/carbofuran (i.e., Furadan) were being used to poison wildlife, via testing by third party (i.e., independent) laboratories.

Mr Brook also called on FMC to establish a 'human equality declaration', whereby FMC should establish its own corporate social responsibility principles to treat all people equally (as this relates to potential human exposure to its products) by using the United States as its benchmark for exposure standards. This declaration would set the direction for which FMC would encourage all users and developing nations to adhere to the US standards set for human exposure, which are currently much lower and less tolerant than those agreed in many developing nations.

Once a shareholder proposal is filed, the burden falls on the corporation to demonstrate why the proposal should not be adopted, and hence the information therein should not be presented to shareholders for a vote regarding whether or not to adopt its contents during the annual meeting. FMC objected to Mr Brook's shareholder proposal and sought to exclude it from the annual proxy statement on the basis that:

1. FMC had already substantially implemented most of the elements requested in the shareholder proposal (specifically, that a stewardship programme was already in place).
2. The shareholder proposal contained false and misleading information [Mr Brook had cited the work of a number of contributors to this book, including Mineau and colleagues and Frank and colleages].

3. The proposal raised issues of 'ordinary business', which the SEC has said that, in certain circumstances (unless the proposal raises sufficiently significant social policy issues) such issues can be excluded.

After several filings, to which FMC responded, the SEC determined that it would take no action against FMC should the corporation determine to exclude the proposal. The proposal was ultimately defeated by the SEC using the grounds that it raised 'ordinary business' without raising sufficiently significant social policy issues. The details of the shareholder proposal, the various rebuttals/appeals, and the SEC's ruling on the matter can be found at: http://www.sec.gov/divisions/corpfin/cf-noaction/14a-8/2011/davidbrook022511-14a8.pdf. Mr Brook remains concerned about what he perceives to be a stance of corporate profitability over better corporate responsibility. Although it is true that third party misuse (e.g., poisoning) is not the 'fault' of a corporation, and, as such, does not fall within their remit, such misuse can all too easily occur, and is to an extent inevitable. If such repercussions were being adequately addressed by manufacturers, they would not continue to pose a problem. Instead, the severe repercussions of such misuse could trigger the loss of a number of species, including Kenya's emblematic lions, which one would presume might threaten a corporation's public image.

While Mr Brook's shareholder proposal was not on the FMC annual proxy statement, he is determined to continue to raise this issue in an effort to improve the way that FMC conducts its business. He presented his views at the shareholders annual meeting on 26 April 2011 and will continue to raise this issue in an effort to improve the way that FMC conducts its business. He also intends to examine ways that the United States Congress and the United Nations can be compelled to more actively protect people and wildlife across the world from the dangers of intentional misuse and legal/labeled use of Furadan/carbofuran. The product is manufactured by corporations in both developing and developed nations (e.g., India and China) and, consequently, engaging with industry and its partners within these countries will be central in developing good practice and in helping to protect wildlife and people from misuse.

However, for such engagement to be effective, manufacturers have to show willingness to participate in the process. Though no longer the sole manufacturer of carbofuran, FMC remains its most prominent and vociferous advocate. Indeed, FMC has resisted the numerous rulings made within US courts against carbofuran, addressing increasingly higher ruling authorities. In August of 2006, the US Environmental Protection Agency (US EPA) released its 'Interim Re-registration Eligibility Decision' and concluded that *no* uses of carbofuran were eligible for re-registration, on the basis of ecological and occupational risks. In response, some uses were voluntarily withdrawn and the EPA planned to terminate the remaining uses through its cancellation process. In May of 2009, the EPA issued a final rule revoking all domestic and imported food tolerances for carbofuran, which went into effect at the end of 2009. At this point, FMC and several food industry lobbying groups challenged these decisions and were successful in convincing a federal court to allow some imports containing carbofuran to continue entering the United States. FMC then appealed to the Supreme Court to reinstate domestic food tolerances for carbofuran. In July 2010, the US Court of Appeals for the District of Columbia upheld the US Environmental Protection Agency (US EPA) to ban tolerances of residues of carbofuran on domestically sourced foodstuffs. As of November 2010, then, any formulation or use of carbofuran was therefore cancelled for registration or re-registration within the US. On 30 March 2011, it was announced that FMC (in conjunction with agribusiness lobbyists that included the National Corn Growers Association) intended to appeal the decision to the US Supreme Court. The details of these proceedings can be found at (http://www.epa.gov/opp00001/reregistration/carbofuran/carbofuran_noic.htm and http://www.abcbirds.org/newsandreports/stories/110330.html). On 31 May 2011, the Supreme Court denied the petition put forward, effectively refusing to hear the case and allowing the US EPA's decision to stand. A legal representative of the US wildlife advocacy group Defenders of Wildlife stated that: 'The Court's action means that, in this case, the health and safety of the American people and our nation's wildlife have trumped the profits of powerful corporations'.

In response to this unfolding turn of events, we return to the issue raised repeatedly in Chapter 8, which is that carbofuran is fundamentally unsafe for nontarget wildlife and for people. The question we must all ask ourselves is: why continue to skirt around such a highly preventable cause of nontarget wildlife mortality and human health risks? The answer is that we should not, and must not. There are certainly no easy solutions, but there is an extremely logical one: to ban the product globally. How likely is this to occur? That remains to be seen. Decades of research and regulations have shown that there is simply no other possible solution.

Appendix

This book has documented the use and misuse of carbofuran in parts of Africa, India, the United Kingdom/Republic of Ireland, Europe as well as Latin and North America. It has also detailed the implication of carbofuran in the mortality of thousands of targeted and non-targeted wildlife species. In other parts of the world, it is either less widely used or its use has not been subjected to the same degree of scrutiny. In much of Asia, for example, relatively little has been collated about the manufacture, use/misuse and regulatory management of carbofuran from an agricultural or wildlife mortality standpoint. To help fill in the global use and incident picture and complete the overview of what is known about carbofuran, a brief summary of its use/registration in Israel, Australia and New Zealand is provided here.

Israel is uniquely situated at the junction between Europe, Africa and Asia, and an estimated 500 million passerines and raptors migrate through the country each spring and fall (Shlosberg 2001). Large scale pesticide usage and an almost complete lack of impact monitoring means that organophosphorus and carbamate insecticides probably pose the most serious threats to birds here (followed by second-generation anticoagulant rodenticides; Shlosberg 2001). Carbamates are used less extensively in Israeli agriculture than organophosphorus compounds. Carbofuran has never been registered in Israel but carbosulfan and benfuracarb, which have structural similarities and could degrade to yield carbofuran and metabolites (as discussed in Chapter 1 and shown in Figures 1.2 and 1.3, respectively) *are* approved for use. The main problem with carbamates in Israel has been illegal intentional poisoning with aldicarb and methomyl. In such incidents, wild pigs, foxes and jackals have mostly been targeted because farmers blame them for damage to agricultural activities. These same two insecticides have been used less in terms of malicious poisonings of pet and farm animals. Malicious incidents (up to 100 cases reported per year) are regularly detected by GC/MS examinations of stomach contents or baits at the Kimron Veterinary Institute [A. Shlosberg, personal communication, 2011].

In **Australia**, two products containing carbofuran are currently registered. They are: Furadan 10G (a granular formulation; (http://services.apvma.gov.au/PubcrisWebClient/search.do) and Furadan 360 (a flowable formulation); Australian Pesticides and Veterinary Medicines Authority (APVMA http://www.apvma.gov.au/). In both cases, the registrant is FMC Australasia PTY Ltd (http://services.apvma.gov.au/PubcrisWebClient/search.do). The product was initially registered for use against white rice stem borers and leafhoppers in rice, against budworm (*Helicoverpa*) and common brown leaf hopper in tobacco (to prevent yellow dwarf virus), and to treat nematodes in sugarcane and cereal cyst nematodes (also known as eelworm) in wheat and barley (http://www.apvma.gov.au/products/review/nominated/carbofuran_update.php). One Minor Use permit has been issued to the garlic industry (permit PER 11097, which will expire in May 2012; see http://permits.apvma.gov.au/PER11097.PDF).

Most agricultural chemical products are placed in Schedule 5, 6 or 7, and bear the signal headings of 'Caution', 'Poison', and 'Dangerous Poison', respectively. Carbofuran appears in Schedule 7 of the Standard for the Uniform Scheduling of Medicines and Poisons (SUSMP) and, as such, all products in which it is present as an active ingredient must clearly identify it as a 'Dangerous Poison'. Primarily registered for use in the tobacco industry (which ceased in Australia in 2006), the amount of carbofuran used in the country has since dropped significantly and evidence available to the APVMA indicates negligible use of products containing carbofuran in Australia (http://www.apvma.gov.au/products/review/nominated/carbofuran_update.php).

Carbofuran is listed on the APVMA's Priority Candidate Review List (PCRL) for chemical review in Australia (http://www.apvma.gov.au/products/review/a_z_reviews.php). However, the APVMA must focus its review resources on those agricultural and veterinary chemicals for which the risk is assessed as being greatest. In this context, 'chemical risk' is deemed a function of hazard (i.e., the intrinsic toxicity of the chemical) and the likelihood of exposure (either of humans, as bystanders or

as workers preparing and applying the products, or of the biota in the environment). Since the current use of carbofuran products can be considered negligible, the APVMA has assessed the human health and environmental risks as low and its review priority has been lowered accordingly, even though carbofuran is recognised as a toxic compound. A review would be considered if evidence (e.g., from sales data) indicated that carbofuran products were being used again in Australia. As national agro-veterinary chemicals regulator, the APVMA collects levies (i.e., charges) on the basis of product sales, and so the annual return from the manufacturing company would reveal any such evidence.

Any carbofuran-related incidents of wildlife mortality or domestic animal/livestock mortality reported to the APVMA would have been recorded by the Adverse Experience Reporting Program (AERP: see website at http://www.apvma.gov.au/use_safely/adverse/agricultural.php) or held by State/Territory Departments of Agriculture or the Environment. As of 2011, no such incidents had been reported [L. Davies, (APVMA), personal communication, 2011].

Carbofuran products have been registered in **New Zealand** in the past. Officials at the New Zealand Ministry of Agriculture and Forestry estimated that registration of such products ceased in about the mid 1980s (since records are currently held in a storage site that is not readily accessible; Approvals & ACM; www.maf.govt.nz). As such, it is possible that incidents of carbofuran-related wildlife or domestic/livestock animal mortality have arisen in the country; however, none appear to have been reported. Areas of intensive agriculture do not usually coincide with the habitat of treasured native species such as the kiwi (Apteryx sp.). In addition, species introduced from Europe (e.g., rats, mustelids (stoats, ferrets and weasels), feral cats and possums) have had a far more devastating effect, at a population level, on native New Zealand wildlife than any agrochemical (C. Eason, personal communication, 2011). Wildlife species have been extensively monitored after large-scale possum or rodent eradication programmes to ensure that the measures taken to cull introduced species are not, in fact, harming wildlife (e.g., Bellingham, Towns, Cameron et al. 2010). For further discussion about pest eradication and predator control measures, the reader is referred to the work of Zavaleta (2002), Eason, Fagerstone, Eisemann et al. (2010), and Eason, Murphy, Hix et al. (2010).

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